

KRATZ

A Study of a 60 Horse-Power
Suction Gas Producer

Mechanical Engineering

M. S.

1909

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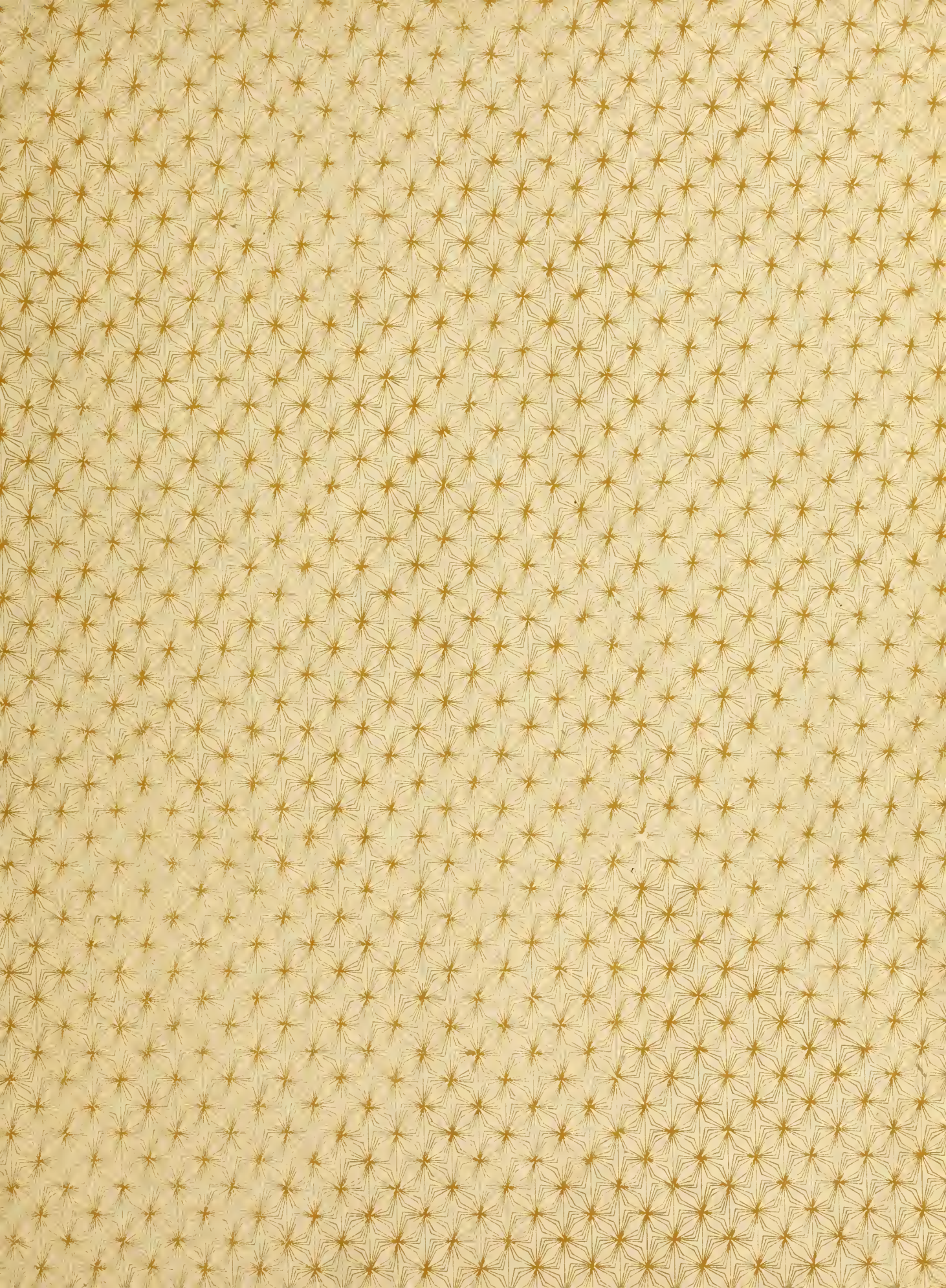
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A STUDY OF A 60 HORSE-POWER SUCTION
GAS PRODUCER

BY

ALONZO PLUMSTED KRATZ

B. S. University of Illinois, 1907

THESIS

Submitted in Partial Fulfillment of the Requirements for the

Degree of

MASTER OF SCIENCE

IN MECHANICAL ENGINEERING

IN

THE GRADUATE SCHOOL

OF THE

UNIVERSITY OF ILLINOIS

1909

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UNIVERSITY OF ILLINOIS
THE GRADUATE SCHOOL

May 1, 1908

I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

ALONZO PLUMSTED KRATZ, B.S., 1907

ENTITLED - A STUDY OF A 60 HORSE-POWER SUCTION GAS PRODUCER

BE ACCEPTED AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF MASTER OF SCIENCE

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Edward C. Schmidt
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Final Examination

K86

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A STUDY OF A 60 H.P. SUCTION
GAS PRODUCER.

PRELIMINARY REMARKS.

The five tests included in the following report, were chosen from a series made under the supervision of Mr. C. M. Garland Instructor in Mechanical Engineering at the University of Illinois, for the Engineering Experiment Station. The data was taken and computations made under the direction of the writer, by members of the Senior class in Mechanical Engineering. In selecting the tests, the chief object held in view was to obtain a series, such that a study could be made of the operation of the producer under different load conditions.

In connection with this work, the following references were used:

Hempel's "Gas Analysis."

"Power Gas Producers," by P. W. Robson.

"Producer Gas and Gas-Producers," by Samuel S. Wyer.

Catalogue of R. D. Wood & Co.

"Technical Thermodynamics," by Zeuner.

"On Air Flowing into Atmosphere thro' Circular Orifices," by R. J. Durley.

TYPES OF PRODUCERS.

The two general types, under which practically all of the producers used in the formation of gas by the process of destructive distillation fall, are the pressure producer, and the suction producer.

In the type first mentioned, the gas is delivered to the

engine under pressure. The air may be drawn thru the fuel bed, and the gas forced to the engine by means of a fan blower placed between it and the producer, as in the Loomis producer, or the air may be forced thru the fuel bed and to the engine by means of a positive mechanical blower, or a steam blower, the latter being the one most generally used. In this case the whole system is under pressure and the gas may be stored in a receiver. A disadvantage to be named in connection with this, however, is that if the system is not absolutely tight, gas is forced out into the fire room, causing a rather dangerous atmosphere for the attendant. The most widely known producers belonging to this class are the Taylor and the Morgan producers, both using the steam blower.

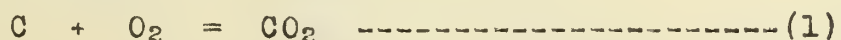
In the suction gas producer the air is caused to pass up thru the fuel bed by the fact that the whole system is under a pressure less than atmospheric. The suction is caused by the forward motion of the engine piston on the intake stroke. This produces a partial vacuum, which the gas rushes in to fill, thus causing a current in that direction, and drawing air into the fuel bed. It may readily be seen, that since the gas is made only when air passes over the fuel, which takes place only with the suction stroke of the engine, the amount of gas generated will be automatically regulated to suit the demand corresponding to the load which the engine is required to meet. The best working conditions for the engine require, that the gas supplied to it be clean, cold, and of uniform quality. In order to accomplish the first two conditions a wet scrubber is installed between the engine and producer. This both cools the gas, and removes the particles of coal dust, soot, and part of the tar. In practically all of the suction producers in use, a

vaporizer is provided, which utilizes part of the sensible heat that would otherwise be lost, by evaporating the water fed to the producer. The National Producer makes still further use of this heat by preheating the air. The vaporizer may be either of the flash type, as in the Dowson and National producers, or of the kind which always contain a body of water, as in the Tangye, Otto, and Crossley producers. The former is under direct control, while in the latter, the air always carries in the amount corresponding to saturation at that temperature, and is generally excessive.

The fact that any considerable resistance to the draft in the producer and scrubber, is detrimental to engine efficiency, excludes the use of an elaborate scrubbing system. Since the bituminous coals and poorer fuels contain a large amount of tar, the removal of which requires rather complicated apparatus, the suction producer has been confined to the use of anthracite, and like fuels containing a low percentage of volatile matter. Another incentive to the use of anthracite is, that the bituminous fuels contain an excessive amount of fusible ash, which forms into clinker and seriously interferes with the operation of the producer.

THEORY OF GAS PRODUCTION.

A simple gas producer consists of a deep bed of incandescent fuel thru which air is passed. As the air strikes the lower part of the fuel bed, the oxygen unites with the carbon in the coal and forms CO_2 after the following reaction:-



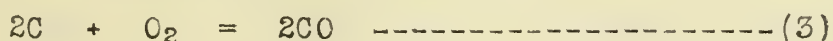
For every lb. of carbon thus consumed, 14540 B.t.u. are liberated. This heat serves to raise the layer of fuel above, to incandescence, and as the CO_2 passes thru it, another reaction takes place as

follows:-



This reaction is influenced both by temperature, and the velocity with which the gases pass over the carbon. At the low velocities prevailing in a producer, and at temperatures above 1650°F, it is probable that the combination occurs in much greater quantities than the dissociation. Therefor, in the theoretical discussion, the reaction will be considered as taking place in the one direction only. Reaction (2) requires 5740 B.t.u. for every lb. of C entering into the reaction. This heat is absorbed from that given off in reaction (1). The net result of these two reactions is, that two lb. of C are consumed and 8,800 B.t.u. liberated.

Chemists are not thoroughly agreed, however, as to whether the process takes place as outlined above, or whether the C burns directly to CO, due to insufficient air supply for complete combustion, following the reaction:-

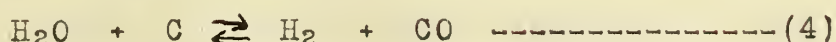


In either case the result is the same. That is, 2 lb. of carbon are consumed, and 4.66 lb. CO formed, with the evolution of 8,800 B.t.u.

A simple calculation shows that the heat value of the CO thus formed, represents about 70% of that of the carbon. The other 30% goes into raising the temperature, and into radiation and conduction, so that the temperature of the producer would soon rise beyond reasonable limits.

A means of saving part of this 30% loss, and of keeping the temperature within reasonable limits, is to utilize this heat in decomposing water. The O₂ thus liberated unites with carbon, while

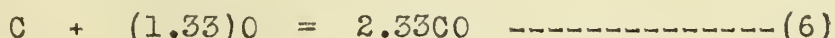
the H_2 goes directly into the gas. These reactions may take place in either of the following ways:-



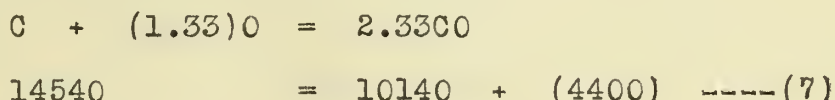
Here again at temperatures above 1650°F the reaction (4) predominates, and the equilibrium is such that the mixture is largely H_2 and CO .

A comparison of the theoretical amounts of the quantities involved when (4) and (5) take place in conjunction with (3), may be obtained as follows:-

(3) represents the combined effect of (1) and (2), and, in order to show the weights of the other quantities when 1 lb. of carbon enters into the reaction, may be written:-

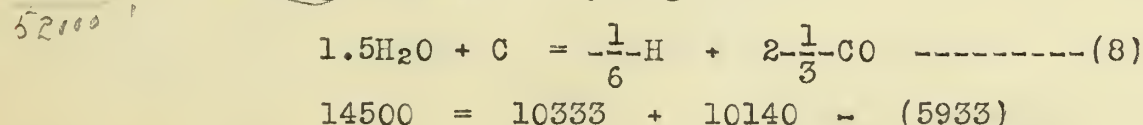


Making a heat balance in the above equation gives:-



That is 4400 B.t.u. are liberated by the above reaction.

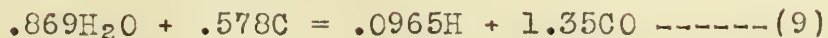
Writing (4) for 1 lb. of carbon and making a heat balance, using 62000, ^{Low} or the High value for hydrogen:-



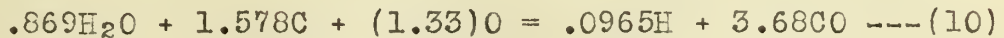
From this, (8) requires 5933 B.t.u. for the reaction. The water entering into (8) must be raised from about 60°F and vaporized.

Every lb. used takes 1118 B.t.u. Hence $1.5 \times 1118 = 1677$, must be added to the heat required, thus making a total of 7610 B.t.u. absorbed by reaction (8). The heat furnished for this purpose is the 4,400 B.t.u. given by reaction (6). Therefore, the weights of the

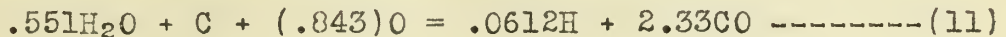
quantities which can be formed, are only $\frac{4,400}{7610}$ of those given in equation (8) or:-



Taking equations (6) and (9) together, that is adding them:-



For a unit weight of carbon this becomes:-



The heat equivalent of each side of (11) is practically 13930.

Knowing the specific weight of O at 62°F and 30"Hg = .08418, of H = .0053, and of CO = .07262, and that air = .79N and (.21)O, the following may be computed from equation (11):

Composition of gas:-

CO ----- 32.10cu.ft. = 39.4%

H ----- 11.55cu.ft. = 14.1%

N ----- 37.70cu.ft. = 46.5%

Total 81.35 100.0

B.t.u. per lb. of carbon = 13930

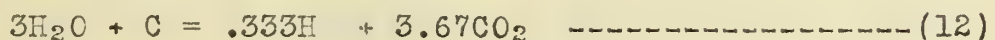
B.t.u. per cu.ft. = $\frac{13930}{81.35} = 171$

Volume of gas per lb. of carbon = 81.35cu.ft.

Weight of steam per lb. of carbon = .551 lb.

Air required per lb. of carbon = 47.7cu.ft. = 3.87lb.

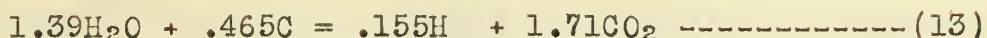
Writing equation (5) to hold for a unit weight of carbon, and again making a heat balance we get:-



$$-3354 + 14540 = 20660 - (9474)$$

That is, the amount of heat required per lb. of carbon for (12) is 9474 B.t.u. As before equation (6) gives 4400 to be used for this purpose. Therefore, the weights of the quantities that can be

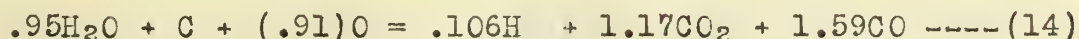
formed are but $\frac{4400}{9474}$ of those given in equation (12), or:-



Combining equations (6) and (13),



For one lb. of carbon this becomes:-



The heat equivalent of each side of (14) is practically 13490.

The specific weight of CO_2 at 62°F and 30"Hg = .1161

Composition of gas:-

CO_2 ----- 10.1 cu.ft. = 10.9 %

CO ----- 21.9 cu.ft. = 23.6 %

H ----- 20.0 cu.ft. = 21.6 %

N ----- 40.7 cu.ft. = 43.9 %

Total 92.7 100.0

B.t.u. per lb. of carbon = 13490

B.t.u. per cubic foot = $\frac{13490}{92.7}$ = 145

Volume of gas per lb. carbon = 92.7 cu.ft.

Weight of steam per lb. carbon = .95 lb.

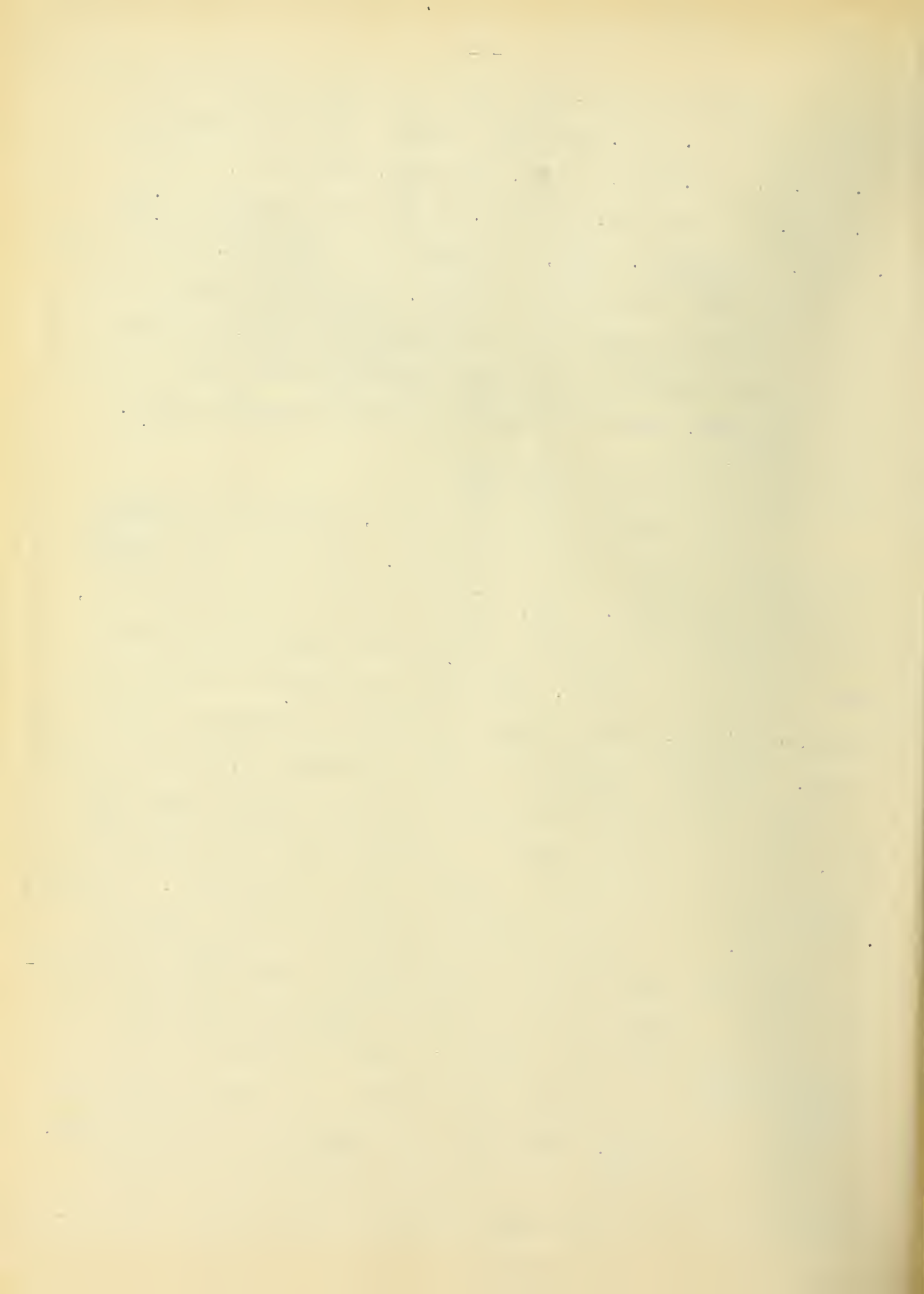
Air required per lb. carbon = 51.5 cu.ft. = 4.17 lb.

Comparing the gas obtained when reaction (4) takes place, with that obtained when (5) takes place, it may be seen that the B.t.u. per lb. of carbon is a little greater in the former case. Also the gas is richer, and the amount of water required is less. It would seem, therefore, that this is the reaction to be desired. Practically, both will take place, but by cutting down the water supply, thus allowing the temperature to rise to about 1650°F, the former will predominate. If too much water is used, the temperature will fall and allow the second to be more in evidence.

From the above, the weight of steam required per lb. of carbon is about .55 lb., for best results. The air required is 47.7 cu.ft. or 3.86 lb. per lb. of carbon, since 1 lb. of air = 12.35 cu.ft. Therefore, every lb. of air should carry in $\frac{.55}{3.86}$ or .142 lb. of moisture. This, of course, is a theoretical value, and only holds where pure carbon is burned. The correct amount can be easily computed for coal of any given carbon content, by multiplying equation (11) thru by the fraction representing the weight of carbon per lb. of coal, and then following the scheme outlined above.

DESCRIPTION OF PLANT AND APPARATUS.

The plant used for these tests, consisted of an Otto suction gas producer, and coke scrubber. The plant also included a 23 H.P. Otto engine. This, however, was not used in the tests, for in order to eliminate the troubles and complications arising from the use of an engine, and confine the problem to the producer alone, a Schutte-Koerting steam ejector was installed to produce the draft. A possible objection to such a procedure is, that the engine produces a fluctuating suction and consequent velocity thru fuel bed, while the ejector produces a constant one, thus leading to a claim that the conditions of operation are not identical. A recent work of Dr. J. E. Clement upon the equilibrium of the reaction $C + CO_2 \rightleftharpoons 2CO$, under different conditions of temperature and velocity, brought out the fact that while for any given temperature the CO present was materially reduced at great velocities, at the low velocities probably existing in a producer, the amount present was practically constant. From this, the conclusion is at once drawn, that small variations in the suction as produced by the engine, would have no appreciable effect upon the composition of the gas,



and that the use of the ejector is justified. The advantages to be derived from the use of the latter are:- (1) That the conditions are under more direct control, and may be maintained uniform throughout a test. (2) The liability of delays on starting, and necessity for shutting down during a test are reduced to a minimum. (3) The necessity of working up an engine test in connection with the producer test is eliminated. (4) It isolates the producer and increases the probability of drawing correct conclusions.

The construction of the producer may be seen from Plate I. Holes were drilled as shown, to permit the insertion of a thermocouple for measuring the temperature of the fuel bed. The holes were in the following positions with reference to the grate:- The top one was in what was called zone #1, and was 24ins. above the grate, the next one, or zone #2, was 18ins. above the grate, the third or zone #3, was 9ins. above the grate, and the fourth or zone #4, was 3ins. above the grate.

Plate II shows the arrangement of the plant and principal instruments. The producer and first scrubber require no special mention. A sample tube was placed in the outlet pipe of the producer for the purpose of determining moisture. The apparatus for doing this consisted of a Kip generator filled with calcium chloride, and so arranged that gas could be drawn in at the bottom and passed over the chloride and out at the top. The volume of gas going thru the apparatus was measured by means of a small meter. This sample was drawn continuously by means of a small aspirator connected in series with the meter and dryer.

The temperature of the gas as it left the producer, was measured with a Platinum-Rhodium thermo-couple. One junction was

protected by a quartz glass tube, and inserted in a thermometer cup at the point shown. The other ends of the wires were soldered to the galvanometer leads, and their junctions kept in a bath of melting ice. The galvanometer used was a Siemens-Halske millivoltmeter, calibrated in both degrees C and millivolts. All the other temperatures were taken by means of mercury thermometers at the points indicated on Plate II, with the exception of the temperature thru the fuel bed. This was taken with a Pt.-Rh. couple similar to the one used in the outlet pipe, the two being connected to a double throw switch, so that the same galvanometer could be used with each. For protection, this couple, after having the two wires insulated by means of a small porcelain tube placed on one of them, was inserted into a quartz glass tube, which in turn was placed in an iron tube. The iron tube was then inserted into the different parts of the fire. Even this was not sufficient, for the iron melted in several cases and made the measurements difficult and rather unsatisfactory.

The ejector was placed after the first scrubber, and after drawing the gas from here, ejected the mixture of gas and steam into a condenser. This was constructed similar to the first scrubber but smaller. No record was kept of the water used by this scrubber, or of the temperatures attained in it, as it was regarded as extraneous to the plant. Up to this point all of the pressures were less than atmospheric, from here on they were greater. From this scrubber the gases were forced thru a separator and into a large dryer, which consisted of a tank filled with straw, and inverted into another tank partly filled with water to act as a seal. The pipe from the scrubber passed to within a few inches of the bottom of this tank, while the one leading to the meters went but

a few inches thru the top. The straw offered a large surface for the purpose of condensing out the moisture. From here the gas passed thru two Westinghouse gas meters, connected in parallel, and went to the waste pipe. In order to facilitate calibration, these meters were arranged so that either one could be blanked off from everything else, and thrown into series with a gage box and thin plate orifice. A pipe from the air compressor was connected in, so that the meter could be either calibrated with air from this source, or by using the ejector. In order to check the amount of air used by the producer, an orifice was placed in the intake, and was calibrated by comparing with the meters and the gage box.

As all of the pressures were low, they were taken by means of manometers. All the manometers were placed upon a single board, and were connected to the points indicated on Plate II by means of piping.

A small meter served to measure the water used by the first scrubber. That fed to the vaporizer was taken from a tank on scales. A flexible hose connected this tank with the pipe leading into the top of the vaporizer. The overflow was caught in a similar tank on scales and the amount used was given by the difference.

In test #15 the arrangement was modified somewhat, in that the vaporizer was blanked off so that no air could be taken across it. An opening was then made in the ash pit to admit air, and steam was piped into the pit from the high pressure main. A box union holding a $3/32$ inch orifice was placed in this line, and a gage used to measure the pressure behind the orifice. As considerable of the steam condensed in the ash pit, a pipe was arranged to take care of this so that it could be weighed. This also permitted

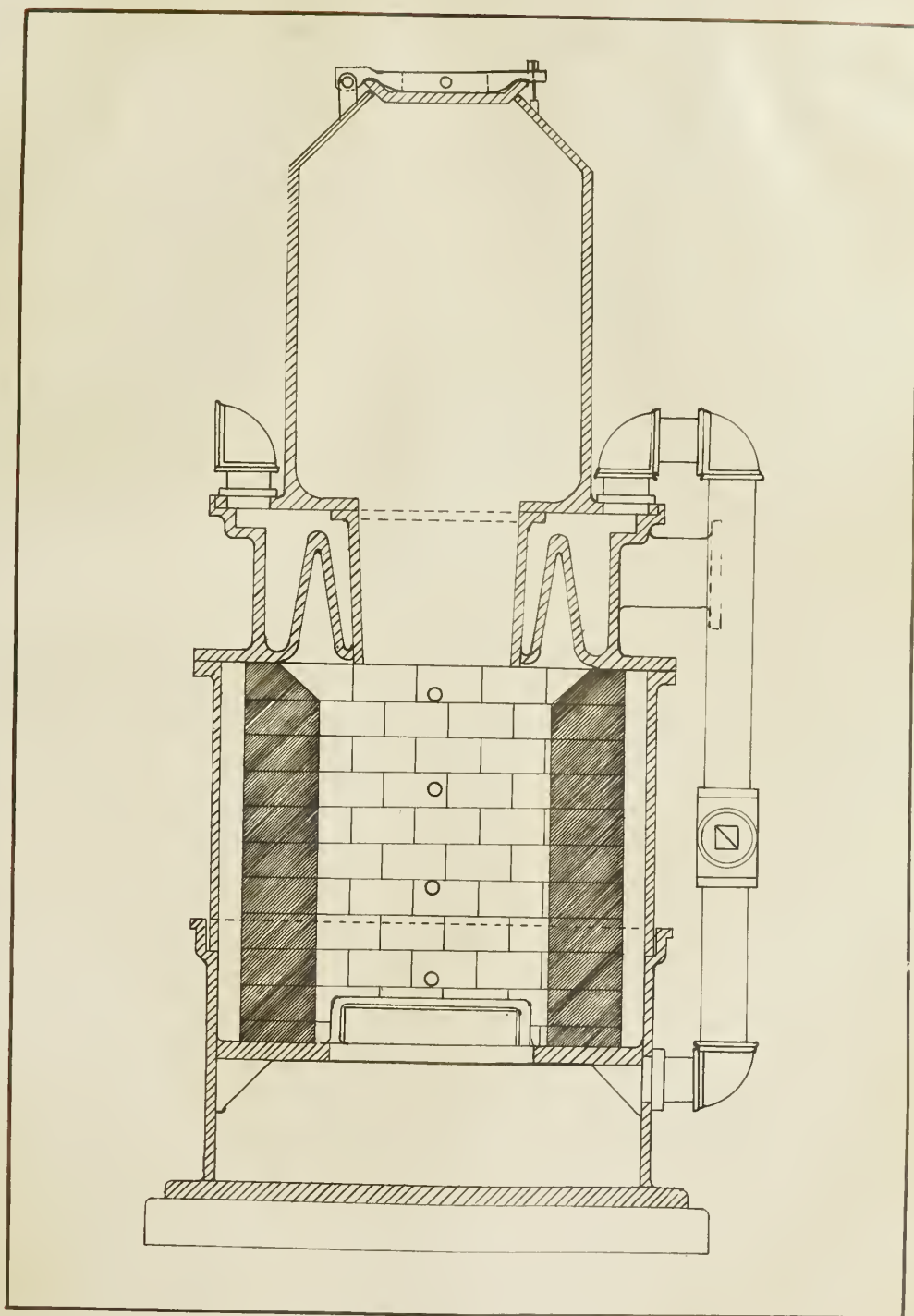
the use of the feed water tank on scales, and the overflow tank on scales to be discontinued.

The gas sample for analysis was collected by means of aspirator bottles similar to those used in any boiler test. The sample for the Junker calorimeter was drawn from the same tube as that for analysis, both being operated continuously. The gas sampler consisted of four perforated tubes extending into the gas main. These were all brought to a common chamber, consisting of a short piece of two inch pipe capped at both ends and bearing a nipple to which the rubber tubes from the Junker calorimeter and aspirator bottles could be attached. As the gas was cold at the point where the sample was drawn, there was no objection to using iron pipe for the nozzles inside the gas pipe. Since the Junker calorimeter is a standard piece of apparatus, it is not deemed necessary to describe it.

The Hempel apparatus was used in making all analyses. It consists of a long measuring burette with a leveling tube, and a number of pipettes containing reagents into which the gas is forced. The absorbing agents used were: KOH. solution for the CO_2 , potassium pyrogallate solution for the O_2 , and ammoniacal cuprous chloride for the CO. The CH_4 and H_2 were determined by exploding a sample in an explosion pipette. The amount of H_2 necessary to cause an explosion was obtained by the electrolytic dissociation of water. One pipette was arranged with both electrodes in the same chamber, and produced oxy-hydrogen, ready for an explosion, which was added to cause the combustion. As this was already in the proper uniting proportions, it would all disappear upon the explosion, and would not affect the other constituents in any way but to raise the

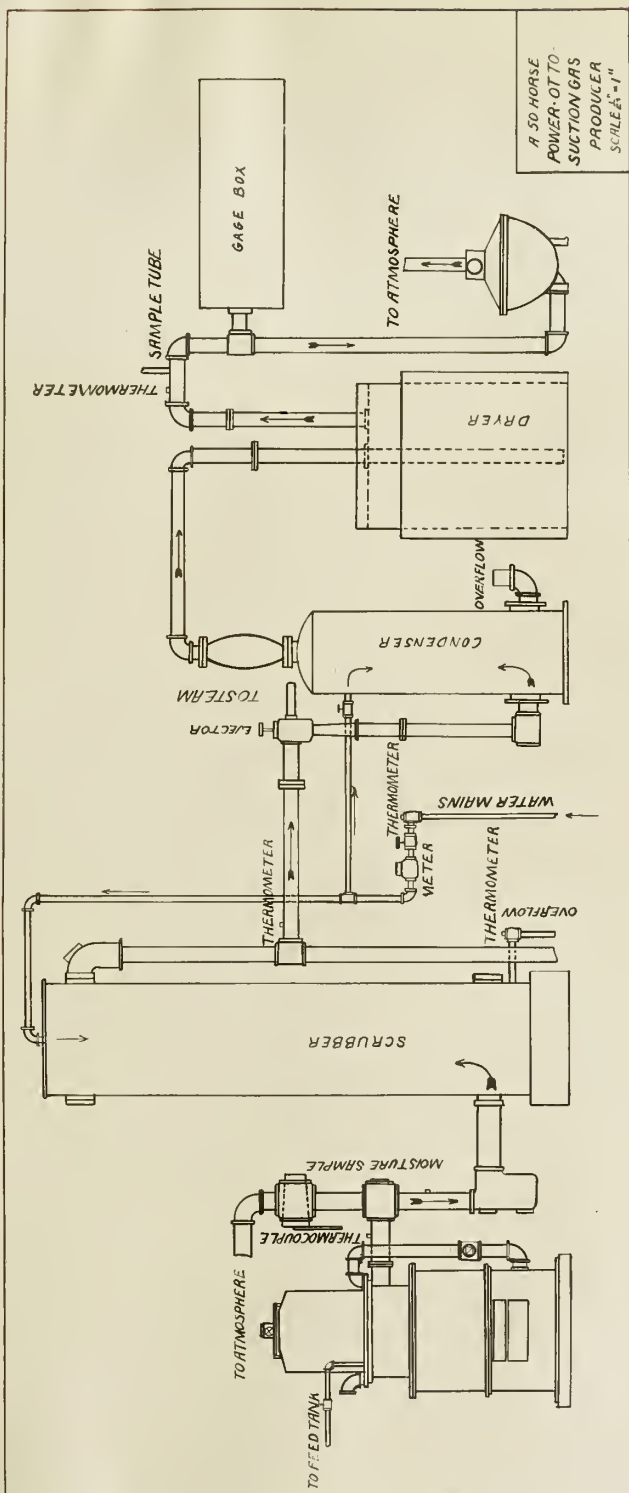
temperature up to the combustion point. It was, therefore, not necessary to measure the amount added. The oxygen added to unite with the CH_4 , and H_2 , was obtained in the same manner as the oxygen, except that the collecting chamber contained the positive electrode alone. By use of this arrangement, it was found that the determinations of CH_4 , and H_2 , could be made to check within less than one percent.

PLATE I.



SECTION OF PRODUCER

PLATE II



ELEVATION OF PLANT

METHOD OF CONDUCTING TESTS.

Before each test the coal and refuse remaining from the test before was taken from the producer, and all of the clinker broken loose from the lining. The fine dust was cleaned from the bottom of the scrubber, and the plant overhauled generally to make sure it was in good working order. A layer of kindling and inflammable stuff was then placed in the producer, and several large buckets of coal poured in. When all was ready the ejector was started, a valve turned, putting the producer in connection with the ejector, and shutting it off from the waste pipe, and a match applied. It was then allowed to run until it was thoroughly warmed up, and the gas would burn at the Junker. As soon as it would do this, the fire was cleaned, the ash removed from the ash pit, the producer filled to the top of the magazine, and the test declared started. From each shovel-full of coal put into the producer at this time, a small amount was shaken into the sampling can. The condition of the fire and the density of the fuel bed was noted. Just before declaring the test started, the ejector was adjusted until the amount of gas decided on for that particular test was flowing. This could be closely approximated by noting the pressure at the meters. Immediately upon starting, readings were taken of the following:- Pressures; at the meters, in the ash pit, at the producer outlet, and behind the orifice; temperatures; at meters, of gas leaving the producer and the scrubber, of the fire-room, and of water entering and leaving the scrubber and vaporizer; initial reading for gas and water meters, as well as initial readings for the tanks on scales.

As soon as the gas would burn again the Junker calorime-

ter was started. This was operated over a period of time required to fill an 8 liter measuring jar, usually about a half an hour. All the temperatures were read four times during this period, while the meter was read only at the beginning and when the jar was just full. As soon as possible, another set was started, this being continued throughout the test. While the Junker was being put into operation, a sample for analysis was being started. These were generally timed so as to draw gas continuously over a period of from an hour to two hours, depending somewhat on the length of test to be run. In making the analyses, the method recommended by Hempel was followed, with the exception of the use of the oxy-hydrogen for the explosion pipette.

As soon as practical, the small dryer for determining the percent of moisture in the gas, was weighed, and connected between its meter and the sampling tube. An initial reading was then taken of the meter, and the aspirator started. This was then allowed to run until the close of the test, when the final weight of the dryer, and a final meter reading were taken.

Care was taken during the test to keep the conditions as nearly uniform as possible. It was found necessary to watch the water level on the meters, because moisture would condense in them and raise the level. This was eliminated to a considerable extent, however, by using enough water in the condenser to keep the temperature of the gas entering the meters at 70°F or lower. A gage glass was put in the condenser, so that the water level could be kept below the entrance of the ejector, for when it rose above this point the pressures became erratic. Any coal put in during the test was weighed, and samples taken, while the ash taken out on cleaning the

fires was stored in cans until the end of the test. The temperature thru the fuel bed was taken as the opportunity offered.

In closing the test, the fire was again cleaned, and the ash drawn. Coal was then weighed in, until the producer was full to the top of the magazine, care being taken that the fuel bed was in as nearly the same condition as it was at the start, as possible. The ash and refuse was then weighed, and samples of coal and ash ground and bottled to be sent to the chemist.

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Results of Gas Producer Trials.

1. Test Number - - - - -	5	7	6	8	15
2. Date of Trial - - - - -	1-29-08	1-1-09	1-30-08	1-2-09	3-20-09
3. Duration of Trial, Hrs. - - - - -	8	9	9	9	15
4. Kind of fuel- - - - -	Anthracite for all tests.				
5. Commercial name of fuel - - - - -	* See last result sheet				

Dimensions and Proportions

6. Dimensions of grate - - - - -	15"x16"	-----	-----	-----	-----
7. Grate area, sq. ft. - - - - -	1.666	-----	-----	-----	-----
8. Depth of fuel bod, ft.- - - - -	2.21	-----	-----	-----	-----
9. Area of fuel bed, sq. ft. - - - - -	1.767	-----	-----	-----	-----
10. Height of discharge pipe above grate, ft.	2.87	-----	-----	-----	-----
11. Approximate width of air spaces in grate ins. -	0.5	-----	-----	-----	-----
12. Area of air space sq. ft. - - - - -	0.722	-----	-----	-----	-----
13. Prop. of air space to whole grate area, %/o	43.33	-----	-----	-----	-----
14. Area of discharge pipe, sq. ft. - - - - -	0.165	-----	-----	-----	-----
15. Water heating surface in vaporizer, sq. ft. - -	2.074	-----	-----	-----	-----
16. Outside diameter of shell, ft.- - - - -	2.83	-----	-----	-----	-----
17. Length of shell from base to top of magazine ft.	7.13	-----	-----	-----	-----
18. Ratio of water heating surface to grate area-to 1	1.25	-----	-----	-----	-----
19. Ratio of minimum draft area to grate area 1 to--	2.32	-----	-----	-----	-----

Average Pressures.

20. Corrected Barometer reading, ins. Hg. - - - - -	29.339	29.593	29.312	29.460	29.098
21. Draft in ash pit, inches water- - - - -	1.03	2.20	0.64	0.62	0.0
22. Suction at producer outlet ins. water - - - - -	11.1	6.95	1.64	1.64	0.388
23. Suction at orifice, inches water- - - - -	0.488	1.14	0.364	0.321	-----
24. Pressure at meters, inches water- - - - -	5.20	5.59	1.51	1.61	1.57
25. Vapor pressure at meters, ins. Hg.- - - - -	3.69	1.44	.814	.918	.714
26. Absolute pressure of dry gas at meters, ins. Hg.	26.03	28.56	28.61	28.66	28.50
27. Steam pressure, lb. per sq. in. - - - - -	---	---	---	---	138

Average Temperatures

28. Of fire room, deg. F.- - - - -	63.7	70.1	66.8	70.3	72.5
29. Of steam, deg. F- - - - -	212	212	212	212	359.6
30. Of feed water entering vaporizer, deg. F - - -	59.3	59.9	61.4	60.9	---
31. Of overflow deg. F. - - - - -	200.7	204.3	189.5	192.9	200
32. Of water entering scrubber, deg. F. - - - - -	57.0	55.5	56.8	56.6	55.3
33. Of water leaving scrubber, deg. F. - - - - -	157.0	131.6	99.4	96.8	90.7
34. Of gases leaving scrubber, deg. F. - - - - -	92.7	78.8	70.1	68.1	79.2
35. of gases leaving producer, deg. F. - - - - -	1213	1104	833.5	991.1	746
36. Of gases entering meters, deg. F. - - - - -	122.7	90.7	73.1	76.7	69.2

F U E L.

37. Size and condition - - - - -	Chestnut #5,6,7 & 8 dirty; #15 Clean				
38. Weight of coal as fired, lb. - - - - -	950	669	382	318	556
39. Percentage of moisture in coal - - - - -	1.97	2.40	2.40	2.10	4.22
40. Total weight of dry coal fired lb. - - - - -	932	653	373	311	532
4L. Total ash and refuse, lb. - - - - -	325	177	91.5	69.0	161
42. Quality of ash and refuse- - - - -	Contained chinker - - - - -				
43. Total weight of combustible, lb. - - - - -	579	437.8	257.5	217.8	375.8
44. Percentage of ash and refuse in dry coal, % - - - - -	34.90	27.15	24.54	22.20	30.30

Proximate Analysis of Coal.

45. Fixed carbon, % - - - - -	79.01	78.93	79.11	79.82	74.44
46. Volatile matter, % - - - - -	6.23	6.12	5.58	4.95	8.30
47. Moisture, % - - - - -	1.97	2.40	2.40	2.10	4.22
48. Ash, % - - - - -	12.79	12.55	12.91	13.13	13.00
49. Sulphur, separately determined % - - - - -	1.28	0.83	0.78	0.80	1.41

Ultimate Analysis of Dry Coal

50. Carbon (C) % - - - - -	81.30	81.30	80.98	80.77	80.21
51. Hydrogen (H ₂) " - - - - -	1.90	2.30	2.30	2.30	2.20
52. Oxygen (O ₂) " - - - - -	1.68	1.87	1.88	1.88	1.71
53. Nitrogen (N ₂) " - - - - -	0.82	0.82	0.82	0.82	0.83
54. Sulphur (S) " - - - - -	1.28	0.85	0.80	0.82	1.47
55. Ash " - - - - -	13.00	12.86	13.23	13.41	13.58
56. Moisture in sample of coal as received, % - - - - -	1.97	2.40	2.40	2.10	4.22

Analysis of Dry Ash & Refuse.

57. Carbon % - - - - -	63.49	63.37	60.16	61.47	43.00
58. Earthy matter % - - - - -	36.51	36.63	39.84	38.53	57.00

Fuel per Hour

59. Dry coal fired per hour, lb. - - - - -	116.5	72.6	41.4	34.6	35.5
60. Combustible consumed per hour, lb. - - - - -	72.45	48.64	28.6	24.2	25.0
61. Dry coal per sq. ft. of grate area per hr, lb. - - - - -	69.8	43.6	24.9	20.7	21.3
62. Combustible per sq.ft. of grate area per hr, lb. - - - - -	43.5	29.2	17.2	14.5	15.0
63. Dry coal per sq.ft. of fuel bed per hr. lb. - - - - -	65.9	41.1	23.4	19.6	20.1
64. Combustible per sq.ft. of fuel bed per hr., lb. - - - - -	41.0	27.5	16.2	13.7	14.2
65. Rate of descent of dry coal thru fuel bed, lb. per ft. per hr. - - - - -	29.8	18.6	10.6	8.85	9.10
66. Rate of descent of combustible thru fuel bed, lb. per ft. per hr. - - - - -	18.55	12.46	7.32	6.20	6.43

Calorific value of Fuel.

67. By Oxygen calorimeter per lb. dry coal, B.t.u. - - - - -	12860	12870	12887	12940	12880
68. By Oxygen calorimeter per lb combustible, B.t.u. - - - - -	20700	19210	18650	18490	18250
69. By analysis per lb dry coal, B.t.u. - - - - -	12925	13130	13070	13060	12954
70. By analysis per lb. combustible, B.t.u. - - - - -	20800	19580	18920	18650	18350

W a t e r

71.	Total weight fed to vaporizer, lb.- - - - -	1054.8	1253.	536.	643	813
72.	Total weight of overflow, lb.- - - - -	354	631	202.	352.	495.
73.	Water actually evaporated in vaporizer, lb.- -	680.8	622.	334.	291.	318.
74.	Total weight of water fed to producer, lb. - -	745.	676.	363.	316	367.5
	a. From vaporizer - - - - -	680.8	622	334	291	318
	b. In air.- - - - -	45.6	37.9	19.3	18.8	26.0
	c. In coal- - - - -	18.7	16.1	9.2	6.7	23.5
75.	Total weight of water decomposed, lb.- - - - -	135	72.2	60.6	41.2	98.1
76.	Weight of water decomposed per hour, lb. - - -	16.87	8.03	6.73	4.57	6.54
77.	Total weight of moisture in gas leaving producer pounds - - - - -	610.1	603.8	302.2	275.1	269.4
78.	Total weight of water unaccounted for - - - - -	120	51.97	4.2	80.7	116.4
79.	% water supplied to producer unaccounted for	16.1	7.69	1.16	25.5	31.65
80.	Ratio of water decomposed to water supplied- -	.181	.107	.167	.130	.267
81.	Ratio of water decomposed to gas generated, lb. water per lb. gas- - - - -	.0247	.0195	.0293	.0235	.0369
82.	Ratio of water decomposed to dry coal fired, lb. water per lb. coal - - - - -	.144	.111	.163	.132	.184
83.	Ratio of water decomposed to combustible consumed, lb. water per lb. combustible - - - - -	.233	.165	.236	.189	.261
84.	Ratio of water decomposed to air supplied lb. water per lb. air- - - - -	.0281	.0227	.0349	.0278	.0453
85.	Ratio of water supplied to dry coal fired- - -	.80	1.04	.974	1.02	.691
86.	Ratio of water supplied to combustible consumed	1.29	1.54	1.41	1.45	.978
87.	Ratio of water supplied to air used, lb. water per lb. air. - - - - -	.155	.212	.209	.214	.170
88.	Total weight of scrubber water - - - - -	19948	22056	18850	17037	23525

Water per Hour.

89.	Water evaporated per hr. in vaporizer, lb.- - -	85.1	69.1	37.1	32.3	---
90.	Water evaporated per hour per sq.ft. of water heating surface in vaporizer, lb.- - - - -	41.0	33.3	17.9	15.6	---
91.	Total weight of water fed to producer per hr., lb.	93.2	75.1	40.3	35.1	24.5
92.	Total weight of scrubber water used per hr.- -	2493	2450	2094	1893	1570

Quantity of Air.

93.	Relative Humidity of air % - - - - -	75	75	80	80	70
94.	% moisture contained in air, % by wt. dry air	.948	1.19	1.13	1.27	1.20
95.	Total weight of dry air used, lb.- - - - -	4800	3186	1738	1478	2165
96.	Dry air per hour, lb.- - - - -	600	354	193	164	144.5
97.	Ratio of dry air used to dry coal fired, lb. air per lb. coal - - - - -	5.15	4.88	4.66	4.75	4.07
98.	Ratio of dry air used to combustible consumed, lb. air per lb. combustible- - - - -	8.28	7.28	6.75	6.79	5.76

G a s

99.	Percentage of moisture in gas leaving producer	11.2	16.3	14.6	15.7	10.13
100.	Percentage soot and tar in gas leaving producer	0	0	0	0	0
101.	Calorific value per cu.ft. standard gas from analysis, B.t.u. (High value)- - - - -	67.36	84.30	93.05	94.80	118.0

102. Calorific value per cu.ft. standard gas from calorimeter, B.t.u. (High value) - - - - -	96.8	95.06	89.56	98.50	113.2
103. Specific weight of standard gas, lb. per cu.ft. -	.07327	.07235	.07127	.07130	.06888
104. Specific heat of dry gas leaving producer - -	.3243	.3198	.3085	.3156	.3078
105. Carbon ratio $\frac{C}{H}$ - - - - -	14.55	13.87	12.67	12.95	12.15
106. Total volume of standard gas, cu.ft. - - - -	74400	51350	29050	24540	38570
107. Volume of standard gas per hr. - - - - -	9300	5705	3228	2727	2570
108. Volume of standard gas per lb. dry coal, cu.ft.	79.8	78.6	77.9	78.9	72.5
109. Volume of standard gas per ^{lb.} combustible, cu.ft.	128.5	117.3	112.8	112.7	102.5
110. Total weight of standard gas, lb. - - - - -	5450	3715	2070	1750	2660
111. Weight of standard gas per hour, lb. - - - -	681.3	412.7	230.0	194.4	177.5
112. Weight of standard gas per lb. dry coal. - -	5.85	5.69	5.55	5.62	5.00
113. Weight of standard gas per lb. combustible - -	9.42	8.49	8.02	8.05	7.08

Gas Analysis by Volume

114. Carbon dioxide (CO ₂) - - - - -	12.32	11.06	10.98	10.33	7.56
115. Carbon monoxide (CO) - - - - -	10.56	13.60	14.73	15.14	20.39
116. Oxygen (O ₂) - - - - -	0.92	0.79	0.63	0.83	0.84
117. Hydrogen (H ₂) - - - - -	8.30	8.48	9.93	8.99	11.02
118. Marsh gas (CH ₄) - - - - -	0.64	1.30	1.33	1.67	1.67
119. Nitrogen, by difference - - - - -	67.26	64.77	62.40	63.04	58.52

Gas Analysis by weight

120. Carbon dioxide (CO ₂) - - - - -	19.52	17.76	17.90	16.77	12.75
121. Carbon monoxide (CO) - - - - -	10.45	15.65	15.00	15.38	21.50
122. Oxygen (O ₂) - - - - -	1.06	0.92	0.74	0.98	1.03
123. Hydrogen (H ₂) - - - - -	0.60	0.62	0.74	0.67	0.85
124. Marsh gas (CH ₄) - - - - -	0.37	0.77	0.80	1.00	1.04
125. Nitrogen, by difference - - - - -	68.00	68.28	64.82	65.20	62.83

Efficiency

126. Grate efficiency - - - - -	75.0	80.7	83.4	84.6	85.4
127. Hot gas efficiency, based on high heating value	67.5	78.2	75.9	81.3	80.2
128. Cold gas efficiency, based on high heating value	41.8	51.5	56.3	57.7	66.4

Cost of Gasification.

129. Cost of fuel per ton delivered in producer room	8.25	8.25	8.25	8.25	8.25
130. Cost per 1000 cu.ft. standard gas, dollars - -	.0526	.0538	0.541	0.534	.0595
131. Cu.ft. scrubber water per 1000 cu.ft. standard gas - - - - -	4.28	6.87	16.37	11.09	9.76

Poking

132. Method of poking - - - - -	From top and bottom				
133. Frequency of poking, hrs. - - - - -	1.25	2	3	3.5	4

Firing

134. Method of firing - - - - -	By hand, without a bell.				
135. Average intervals between firing hrs. - - - -	1.5	2.5	3	5	5
136. Average amount of fuel charged each time, lb. -	190	170	127	160	112

Heat Balance

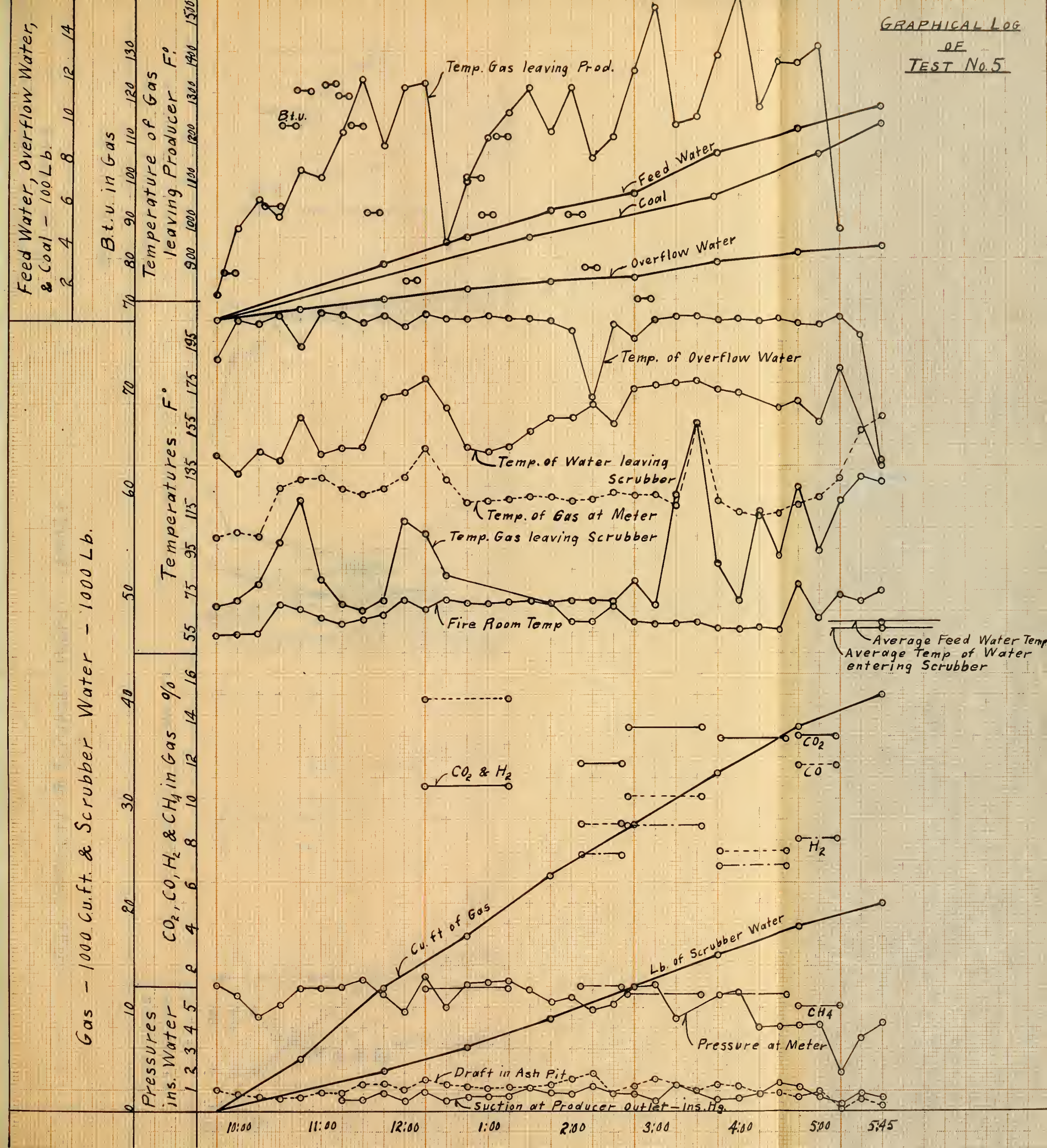
Debit.

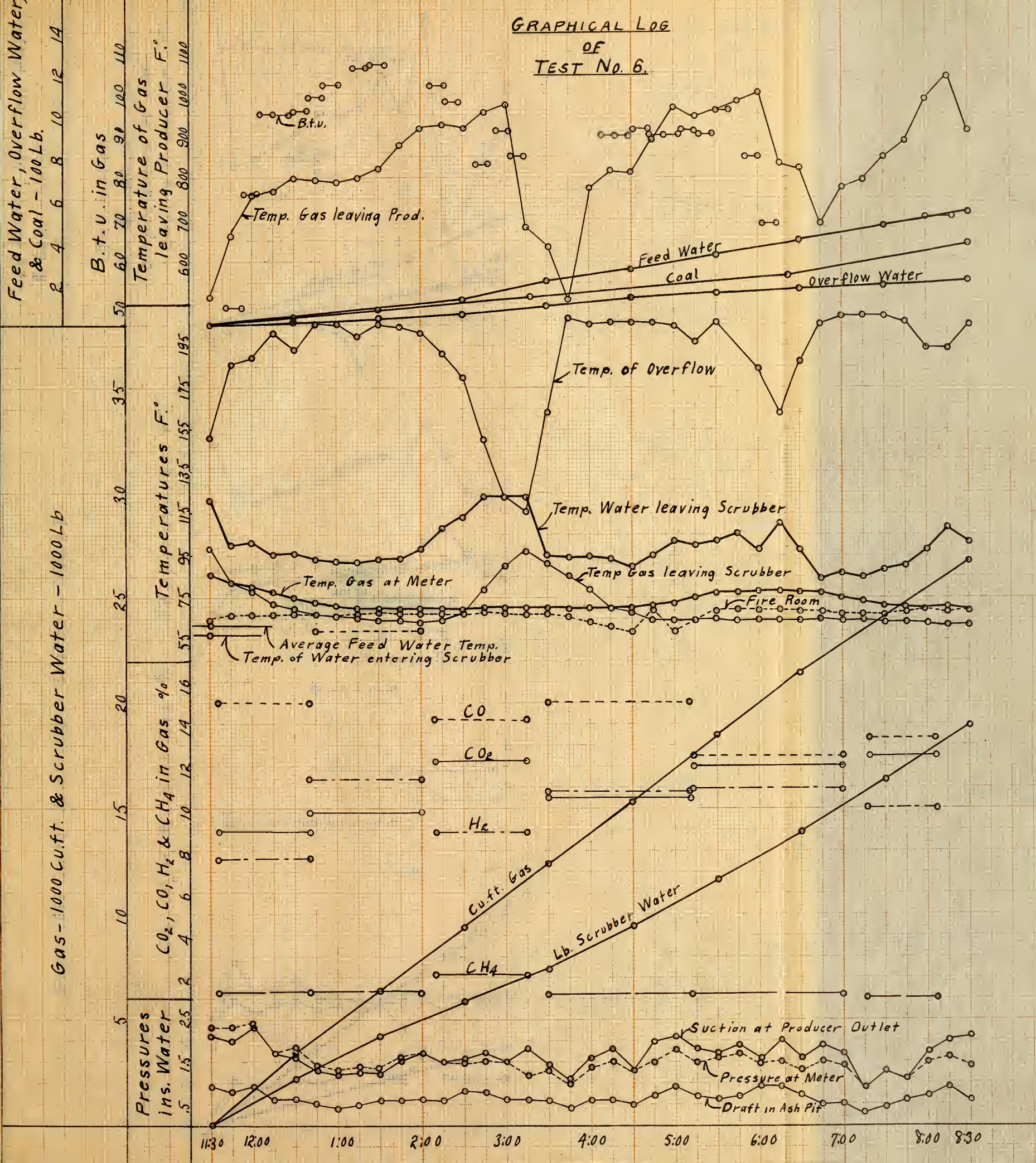
1.	Total heat supplied per lb. of coal, B.t.u.---	12860	12870	12887	12940	12880
2.	Total heat supplied by air per lb. of dry coal, B.t.u. - - - - -	2.1	9.5	5.4	9.5	10.3
3.	Total heat supplied by moisture in air per lb. of coal, B.t.u.- - - - -	1.5	1.9	1.7	2.	1.7
4.	Total heat supplied by moisture in coal per lb. dry coal, B.t.u. - - - - -	---	.2	0.1	0.2	0.5
5.	Total heat supplied as sensible heat in coal, B.t.u. - - - - -	0.4	2.0	1.2	2.0	2.5
6.	Total heat supplied in vaporizer water, B.t.u.	-2.0	-2.0	-0.5	-1.0	+1510
	TOTAL - - - - -	12862	12882	12896	12953	14405

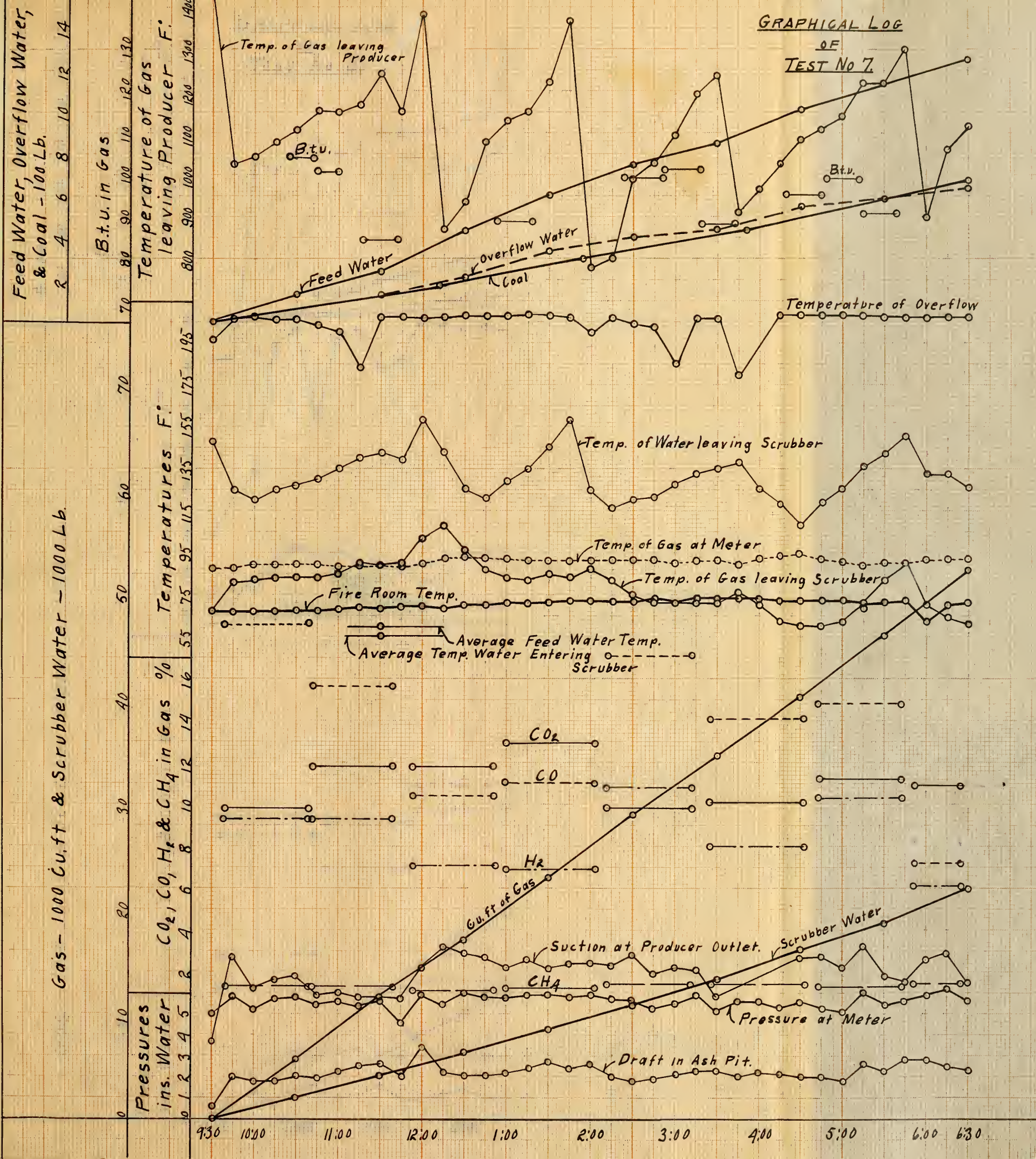
Credit.

1.	Heat contained as sensible heat in gas, B.t.u.	2185	1895	1317	1648	1054
2.	Heat contained in moisture, B.t.u. - - - - -	1125	1528	1205	1400	728
3.	Heat contained in dry gas, B.t.u. - - - - -	5377	6625	7250	7480	8550
4.	Heat in unburned carbon, B.t.u.- - - - -	3220	2498	2146	1984	1892
5.	Heat contained as sensible heat in ash and refuse, B.t.u. - - - - -	----	----	----	----	----
6.	Heat lost in overflow from vaporizer, B.t.u.	53.7	140	70	150	128
7.	Radiation, conduction, & unaccounted for, B.t.u.	899	196	908	291	2053
	TOTAL - - - - -	12862	12882	12896	12953	14405

* Commercial name of fuel- - - - - Philadelphia and Reading for tests
No. 5, 6, 7 & 8.
Lehigh Valley for test No. 15.







STATIONARY POINTS

1. 1000 - 1000 - 1000

2. 1000 - 1000 - 1000

3. 1000 - 1000 - 1000

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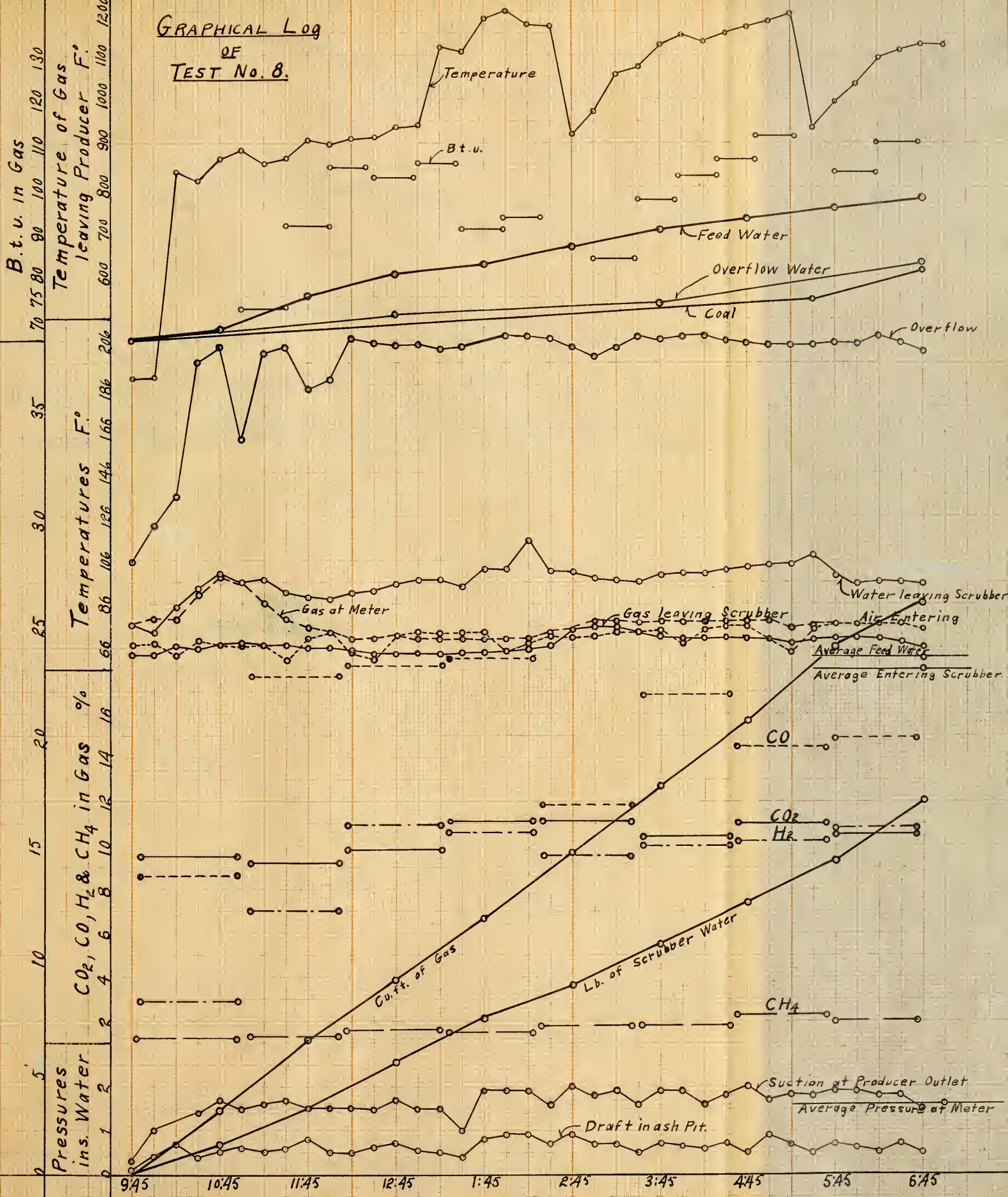
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Feed Water, Overflow Water,
& Coal. - Lb.

Gas - 1000 Cu.ft. & Scrubber Water - 1000 Lb.

GRAPHICAL Log
OF
TEST No. 8.



Gas - 1000 Cu.ft. & Scrubber Water - 1000 Lb.

Coal - 100 Lb.

2 4 6 8 10 12

B.t.u in Gas

100 110 120 130 140 150

Temperature of Gas leaving Producer F°

400 500 600 700 800 900

Pressures

ins. Water

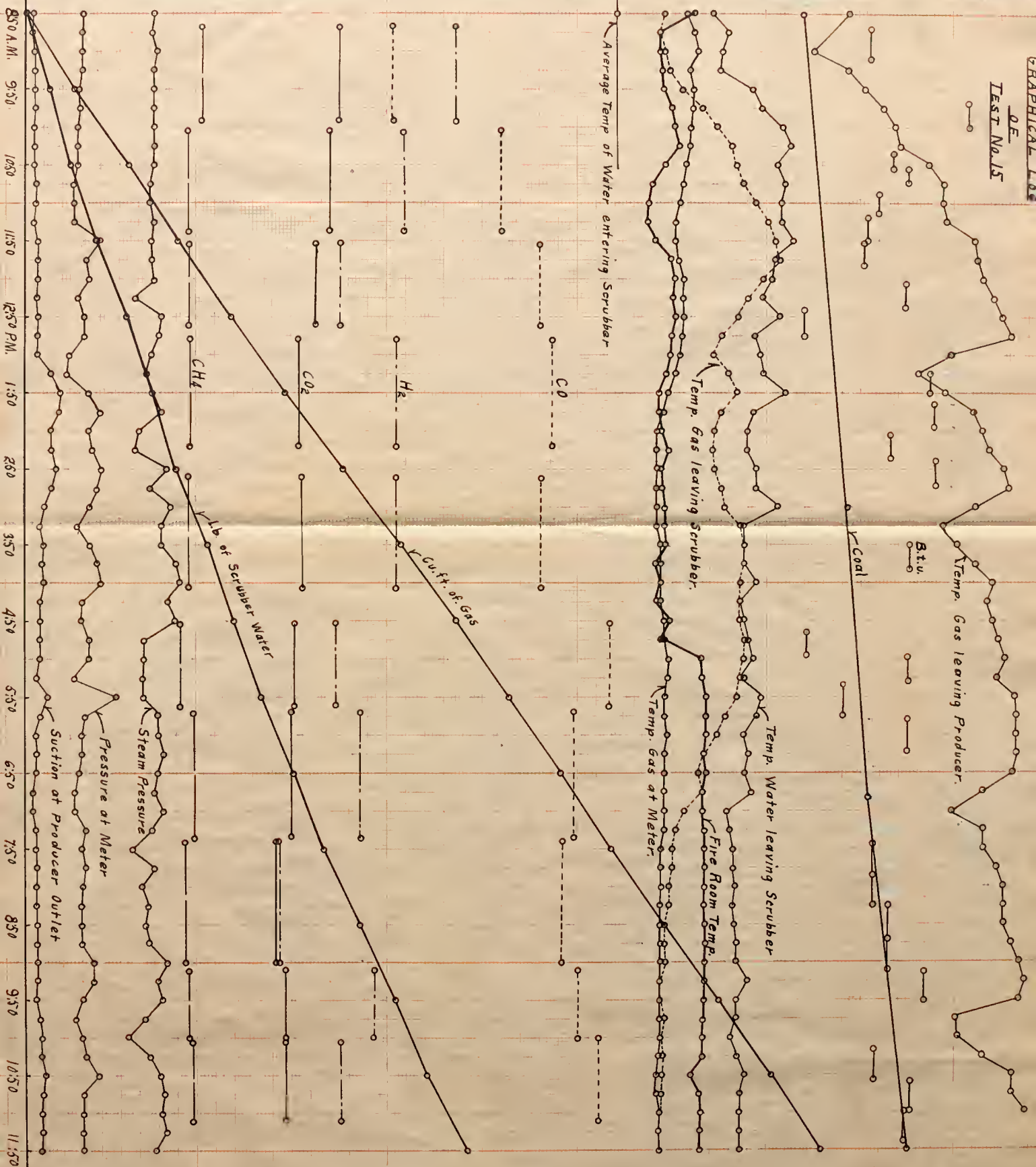
Steam Pressure

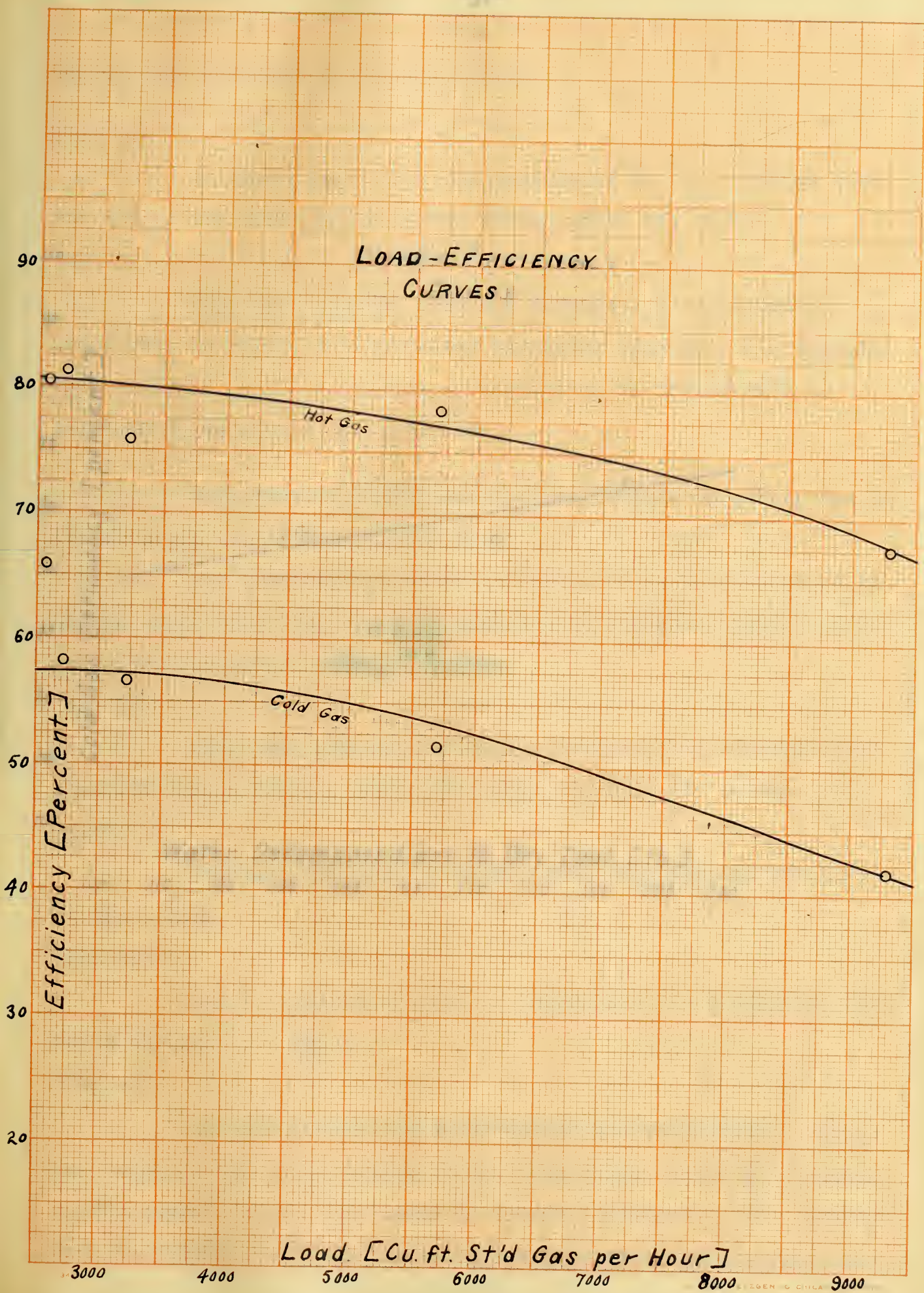
130 140

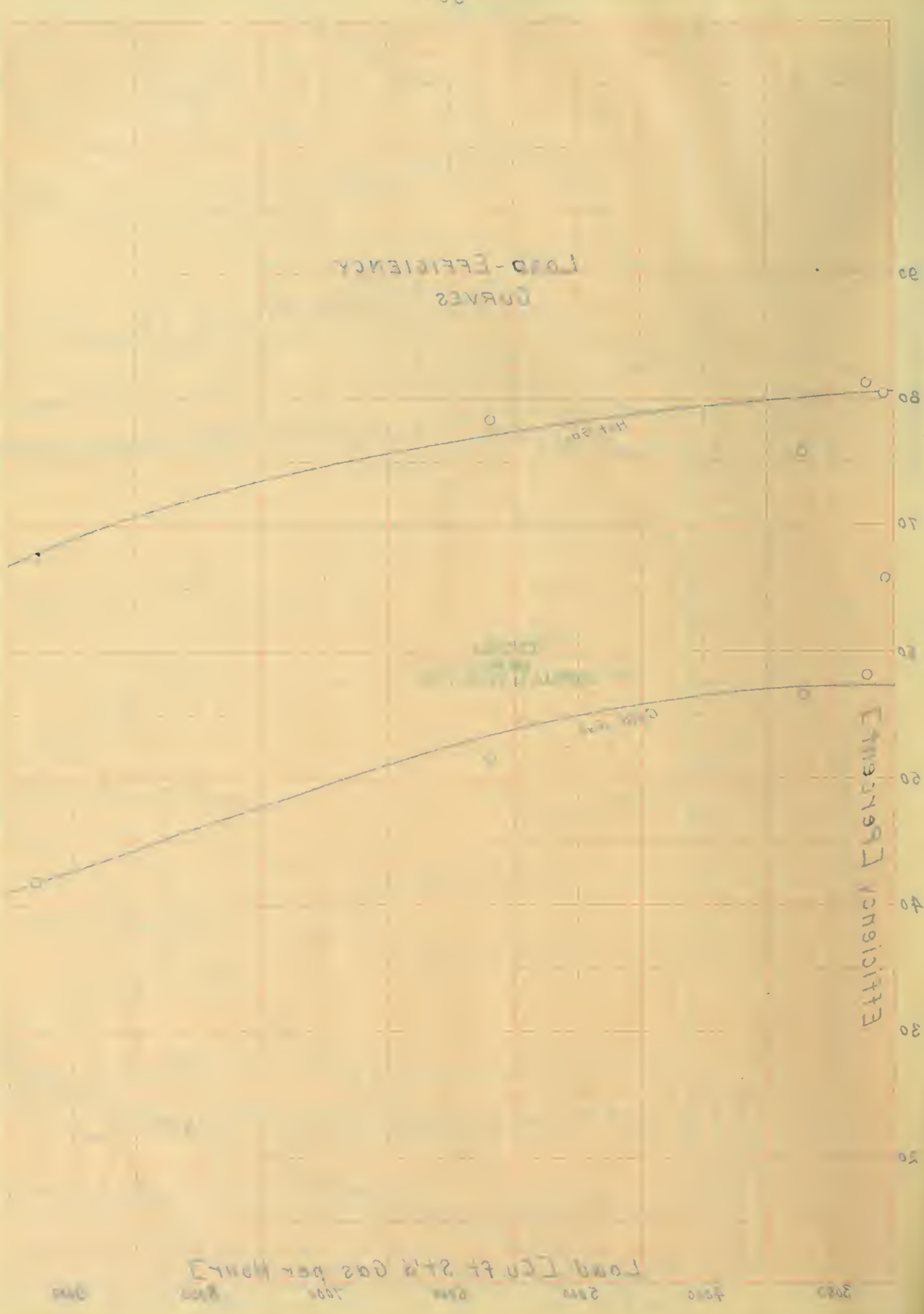
CO₂, CO, H₂ and CH₄ in Gas %

Temperatures F°

65 75 85 95



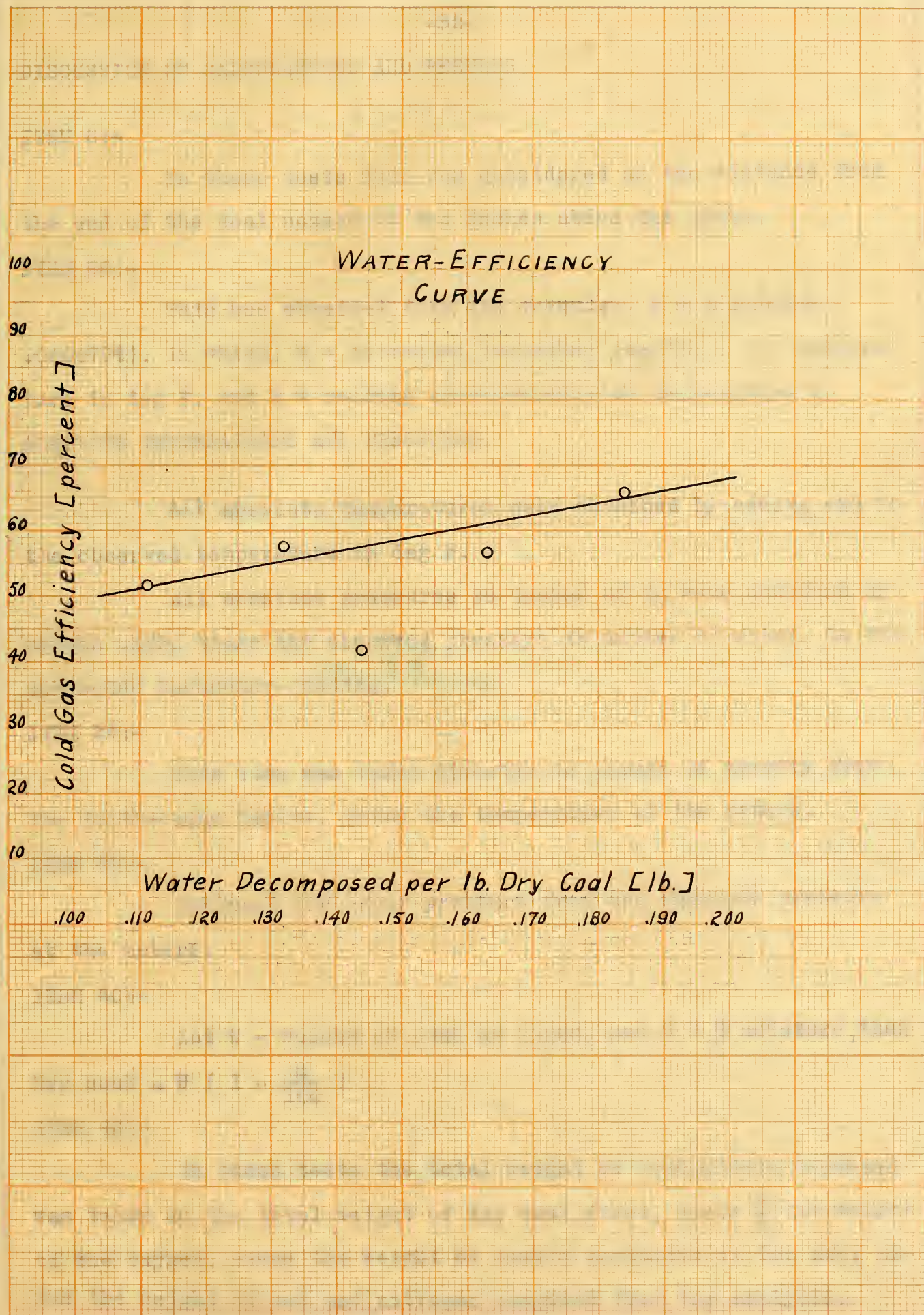




Load-Efficiency
Curves

Efficiency

Load (cu ft gas per hour)



Water Decomposed per lb Dry Coal [lb.]

100	110	120	130	140	150	160	170	180	190	200
-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----

Cold Gas Efficiency [Percent]

WATER-EFFICIENCY
CURVE



DISCUSSION OF CALCULATIONS AND RESULTS.

ITEM 8:-

In these tests this was considered as the distance from the end of the coal nozzle to two inches above the grate.

ITEM 20:-

This was obtained from the formula:- $H = h(1.00254 - .000079t)$, in which, H = corrected barometer reading, t = temperature in deg F. and h = reading corresponding to temperature t .

ABSOLUTE TEMPERATURES AND PRESSURES.

All absolute temperatures were obtained by adding 460 to the observed temperature in deg F.

All absolute pressures in inches of Hg were obtained by adding .0735 times the observed pressure in inches of water, to the corrected barometer reading.

ITEM 25:-

This item was taken directly in inches of mercury from the Smithsonian Tables, using the temperature at the meters.

ITEM 26:-

Subtract the vapor pressure from the absolute pressure at the meters.

ITEM 40:-

Let W = weight of coal as fired, and M = % moisture, then
Dry coal = $W \left(1 - \frac{M}{100} \right)$

ITEM 43:-

In these tests the total weight of combustible consumed was taken as the total weight of dry coal fired, minus $\frac{9}{8}$ the weight of the oxygen, minus the weight of carbon contained in the ash, minus the weight of ash and nitrogen computed from the analysis.

Let W_3 = wt. of combustible, W = weight of dry coal, A = % ash, N the % of Nitrogen, O the % of oxygen, W_2 the weight of ash and refuse, and C the % of carbon in ash and refuse.

$$\text{Then } W_3 = W - \frac{WA}{100} - \frac{WN}{100} - \frac{8}{9} \times \frac{WO}{100} - \frac{W_2C}{100}$$

ITEM 65:-

This is the same as the dry coal per cu.ft. of fuel bed per hour. This seems better adapted to comparing the rate of gasification in different producers than the term "Coal per sq.ft. of grate area", taken from boiler practice, because the depth of fuel bed certainly enters in as a factor in producer work.

ITEMS 68 & 70:-

Let W_3 = weight of dry coal, W_2 the weight of combustible, B_3 the B.t.u. per lb. dry coal and B_2 the B.t.u. per lb. the combustible, Then $B_2 = \frac{B_3 \times W_3}{W_2}$.

ITEM 69:-

$$B = \frac{C \times 14540 + S \times 4000 + (H - \frac{1}{8} O) 62000}{100}$$
 in which
 C = % carbon in dry coal, S = % sulphur in dry coal, H = % hydrogen and O = % oxygen.

ITEMS 71 & 73:-

The wording of these items does not hold strictly for test #15, because instead of using the vaporizer, steam was put in from a high pressure main, thru a 3/32 inch orifice. They still refer to the amount of water used by the producer, however. Item 71 was calculated in this case from Napiers rule, which is:-

$$\text{The weight in lb. per sec.} = \frac{\text{Absolute pressure} \times \text{area in sq.in.}}{70}$$

This holds only when the lower pressure is less than 58% of the high pressure.

ITEM 74b:-

Let W = total weight of air used, M = % moisture in air

by weight, and W_3 the total weight of water carried in by air.

Then:- $W_3 = \frac{WM}{100}$

ITEM 74c:-

Let W = wt. of coal fired, M = % moisture in coal, and

W_3 = weight of water fed with coal.

Then:- $W_3 = \frac{WM}{100}$

ITEM 75:-

This was calculated from the analyses as follows:-

$W = \frac{9 (W_3H - W_2A)}{100}$, in which W = weight decomposed, W_3 = total weight of standard gas, H = % Hydrogen in gas by weight, W_2 = weight of dry coal, and A = % of Hydrogen in coal.

ITEM 77:-

$W = \frac{W_3M}{100}$, in which W = the weight of moisture, W_3 = the total weight of standard gas, and M = the % by weight of moisture in the gas.

ITEMS 78 & 79:-

These merely give the error in the determination of the moisture by use of the calcium chloride dryer.

ITEM 93:-

As this item was not observed, it was necessary to obtain an approximate value from the Weather Bureau for the days on which the tests were run. These values were taken out of doors, and from them an estimate of the relative humidity for the conditions indoors, in an atmosphere where steam was escaping, was made.

ITEM 94:-

The weights of air and moisture in a cubic foot of mixture at different temperatures was obtained from Kent, page 484.

Let p = the % saturation or relative humidity, n = weight of mois-

ture contained in a cu.ft. of saturated air at fire room temperature, and m = weight of 1cu.ft. of dry air at observed temperature. Then $\frac{pn}{100}$ = the weight of moisture in one cubic foot of air used. The % moisture in air by weight = $\frac{pn}{100m} \times 100 = \frac{pn}{m}$.

ITEM 95:-

This was calculated from the amount of nitrogen appearing in the gas. Let N = % by weight of nitrogen in the gas, W = the total weight of gas, W_2 = the total weight of dry coal, N_2 the % by weight of nitrogen in coal, W_3 the total weight of nitrogen in the air supplied, and W_4 = the total weight of air supplied.

The nitrogen in the gas comes from the air used, and from that introduced with the fuel. The total weight in the gas = $\frac{NW}{100}$. That supplied by the fuel = $\frac{W_2 N_2}{100}$. Hence $\frac{NW}{100} = \frac{N_2 W_2}{100} + W_3$. Since .77 of the air is nitrogen $W_4 = \frac{W_3}{.77}$.

$$\text{Hence } W_4 = \frac{NW - N_2 W_2}{77} \quad \text{-----(1)}$$

The weight of air may also be obtained from the amount of oxygen appearing in the gas. Since this was not used, the formula will be given and the derivation omitted.

$W_4 = \frac{1}{.23} \left[\frac{W}{100} \left(\frac{8}{11}A + \frac{4}{7}F + B \right) - \frac{GW_3}{100} - \frac{8}{9}W_2 \right]$, in which W_4 = weight of air used, W = total weight of gas, A = % by weight of CO_2 in the gas, F = % by weight of CO in the gas, B = % by weight of O_2 in the gas, G = % by weight of O_2 in coal, W_3 = total weight of dry coal, and W_2 = weight of water decomposed.

ITEM 99:-

$M = \frac{(W - W_3) 100}{W_2}$, in which M = % moisture, W = total weight of water fed to the producer, W_3 = total weight of water decomposed, and W_2 = total weight of standard gas.

ITEM 101:-

One cubic foot of standard gas, that is gas at a temper-

ature of 62°F or 522° absolute and a pressure of 30"Hg, gives upon combustion, when the products are brought back to this temperature, the following heat quantities:-

$H_2 = 328 \text{ B.t.u.}$; $C_2H_4 = 1480 \text{ B.t.u.}$; $CO = 319 \text{ B.t.u.}$
and $CH_4 = 1010 \text{ B.t.u.}$ From this the B.t.u. per cu.ft. of the given gas may be obtained, by multiplying the above numbers by the amount of the corresponding constituent in a cubic foot.

ITEM 102:-

This is the average of all the calorimeter determinations, each separate determination having been computed.

The calorimeter readings were taken in Centigrade units with the exception of the meter readings and pressure.

Let:- t_5 = temperature of entering water, °C.

t_2 = temperature of leaving water, °C.

r = rise in temperature of water, °C.

W = weight of water used during the interval = 8 liters for all tests.

G_3 = cu.ft. of gas used from meter.

t_3 = temperature of entering gas, °C.

p_3 = pressure entering gas ins.Hg. absolute.

H = heating value per cu.ft. of standard gas (62°F or 16.7°C and 30"Hg.)

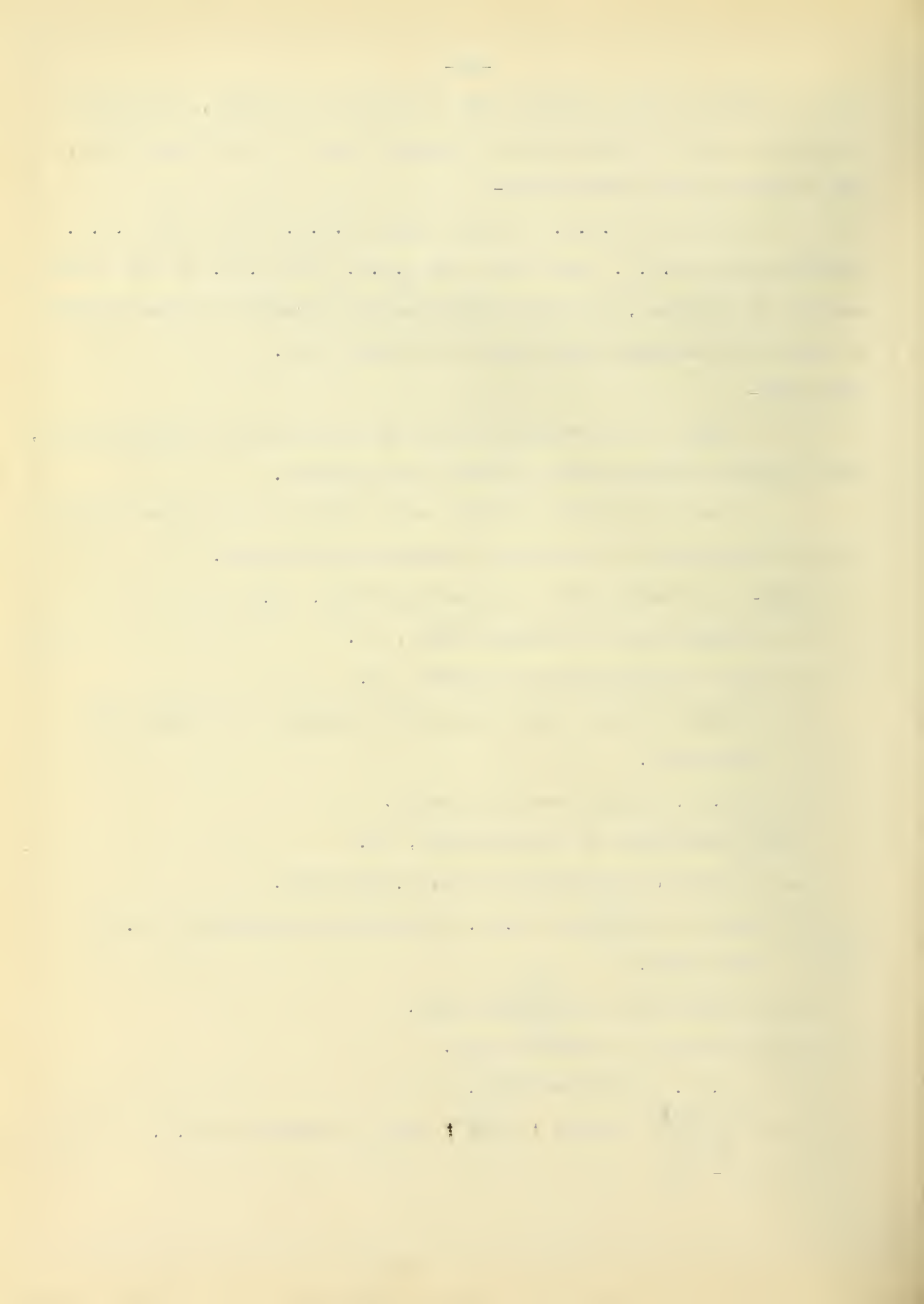
t_4 = temperature of standard gas.

p_4 = pressure of standard gas.

G_4 = cu.ft. of standard gas.

$G_4 = \frac{G_3 p_3 T_4}{T_3 p_4}$ where T_3 and T_4 are in absolute deg.C.

$r = t_2 - t_5$.



$$H = \frac{W \times r \times 3.968}{G_4} = \frac{W \times r \times 3.968}{\frac{G_3 \times p_3 \times T_4}{T_3 \times p_4}} = \frac{8 \times 30 \times 3.968 \times T_3}{G_3 p_3 (16.7 + 273)} =$$

$$\frac{T_3 \times r \times 3.29}{G_3 \times p_3}, \text{ where } 3.968 \text{ is the conversion factor.}$$

This formula holds only when the exhaust products are brought back to 62°. This was not always done, but the error introduced was negligible. There is another error due to the exhaust products carrying out more water vapor than was brought in by the gas and air, but the error due to this is probably less than 1% for temperatures below 80°F.

On account of the fact that the gas flame in the calorimeter was extinguished when the gas was poor, so that a determination was not possible at these times, while the sample for analysis was taken continuously over these periods, the average B.t.u. by the calorimeter was in most cases higher than by analysis.

ITEM 103:-

The specific weights of the following gases at 62°F and 30" Hg are:-

$$CO_2 = .11610$$

$$H_2 = .00530$$

$$CO = .07262$$

$$CH_4 = .04278$$

$$O_2 = .08418$$

$$N_2 = .07400$$

$S = (.1161a + .07262b + .08418c + .0053d + .0428e + .074f) \frac{1}{100}$, in which, a, b, c, d, e, and f, are the percentages by volume of the CO_2 , CO, O_2 , H_2 , CH_4 , and N_2 , respectively.

ITEM 104:-

The specific heats of gases vary with pressure and temperature. As the pressure throughout these tests was atmospheric, only the variation with temperature was considered. The following formulae taken from Zeuner Vol. I. p.147, gives specific heat for

constant volume, C_v

$$\text{CO}_2, \quad MC_v = 6.50 + .00774t \quad \text{-----1}$$

$$\text{H}_2\text{O}, \quad MC_v = 5.78 + .00572t \quad \text{-----2}$$

$$\text{O}_2, \text{H}_2, \text{N}_2, \text{CO}, \quad MC_v = 4.76 + .00244t \quad \text{-----3}$$

$$MC_p - MC_v = 1.9934$$

For the specific heat of marsh gas, CH_4 , the value .6 was used. This is approximate, but as the amount of CH_4 is small, the error is consequently small.

In the above formulae, M is the molecular weight of the gas, t the temperature in deg.C., and C_v the mean specific heat between 0° and $t^\circ\text{C}$. C_p is determined from formula (4). From the above formulae, the analysis by weight of the gas, and the temperature of the gas leaving the producer, the specific heat of each constituent in a unit weight of gas may be determined. The specific heat of the gas will be the sum of that of the constituents.

Substituting the value of MC_v from formula (4), and the value of M, and changing from Centigrade to Fahrenheit, we have from the above formulae:-

$$\text{For } \text{CO}_2, \quad C_p = .19 + .0000977t \quad \text{-----}(a)$$

$$\text{" } \text{H}_2\text{O}, \quad C_p = .426 + .000176t \quad \text{-----}(b)$$

$$\text{" } \text{H}_2, \quad C_p = 3.355 + .000678t \quad \text{-----}(c)$$

$$\text{" } \text{CO}, \quad C_p = .24 + .0000484t \quad \text{-----}(d)$$

$$\text{" } \text{N}_2, \quad C_p = .24 + .0000484t \quad \text{-----}(e)$$

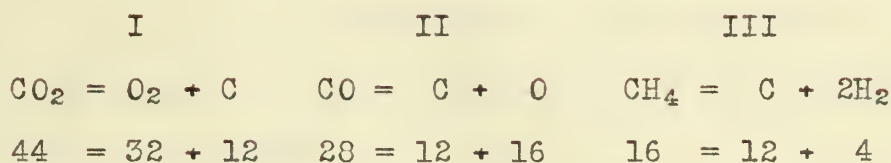
$$\text{" } \text{CH}_4, \quad C_p = .6 \quad \text{-----}(f)$$

$$\text{" } \text{O}_2, \quad C_p = .21 + .0000424t \quad \text{-----}(g)$$

Let a,b,c,d,e,f, and g, represent the mean specific heats of the above gases between 32° and $t^\circ\text{F}$, and A,B,C,D,E,F, and G, the percentage by weight of the respective gases. Then, for dry gas:-

$$C_p = (aA + cC + dD + eE + fF + gG) \frac{1}{100} .$$

ITEM 105:-



The total weight of carbon appearing in a unit weight of the gas from the above, = % by weight $CO_2 \times \frac{3}{1100} + \% \text{ by weight } CO \times \frac{3}{700} + \% \text{ by weight } CH_4 \times \frac{1}{400}$
Hence:- $C/H = \frac{\frac{3}{11}A + \frac{3}{7}B + \frac{3}{4}C}{D + \frac{1}{4}C}$, in which A,B,C, and D, are the per-

centages by weight of the CO_2 , CO , H_2 and CH_4 .

ITEM 106:-

This item was calculated in three ways; viz, from the meter readings, from the heat lost to the scrubber water, and by the analysis of gas and coal. As the value recorded was chosen from the last mentioned way, its derivation will be given below, but for the other two the derivation will be omitted, and nothing but the final formulae given.

By the meter:-

$V = \frac{17.4 Gp}{T}$, in which V = total volume of standard gas, G = total volume measured by the meters, T = the absolute temperature at the meters, and p = the dry gas pressure at the meters = Item 26.

By Heat lost to scrubber water:-

$V = \frac{W_3 t_3 - W_2 [0.6(t - 212) + 1116]}{ST_2 C_p - W_4 H}$ in which V = total volume of standard gas, W_3 = total weight of scrubber water, t_3 = the rise in temperature of the scrubber water, W_2 = the total weight of moisture in gas leaving the producer, t = the temperature of gas leaving the producer, S = the specific weight of gas, T_2 = the drop in tempera-

ture of the gas going thru the scrubber, C_p = the mean specific heat at the temperature of gas leaving producer, W_4 = the weight of a cubic foot of vapor at the temperature of the gas leaving the scrubber, H = the total heat in steam above 62°F at the temperature of the gas leaving the scrubber.

By analysis:-

Evidently the total weight of carbon appearing in the gas should equal the carbon in the coal, minus the weight lost thru the grate, minus the weight lost in soot and tar. The latter is negligible in the hard coal producer.

Let P = % carbon by weight in dry coal.

" W = Total weight of dry coal.

" P_6 = % carbon in the ash.

" W_6 = Total weight of ash.

" W_2 = The weight of carbon that should appear in the gas.

$$W_2 = \frac{PW - P_6 W_6}{100}$$

This carbon is contained in the CO_2 , CO , and CH_4 .

The proportion by weight of C in CO_2 is $\frac{3}{11}$, of C in CO is $\frac{3}{7}$, and of C in CH_4 is $\frac{3}{4}$.

Therefore, the total weight of C in a unit weight of gas will be = $W_3 = (3/11A + 3/4E + 3/7F) \frac{1}{100}$, where A, E, and F, are the % by weight of CO_2 , CH_4 , and CO , from the gas analysis.

The % carbon contained in the gas as CO_2 is $\frac{3/11A}{W_3}$.

The actual weight of this carbon is $\frac{3/11AW_2}{W_3 \times 100}$ since W_2 is the total weight of carbon consumed from the fuel.

One lb. carbon on burning produces 3.66lb. CO_2 .

Then $\frac{3/11AW_2}{W_3 \times 100} \times 3.66$ = total weight of CO_2 in gas.

Let S = the specific weight of the CO_2 at 62° and 30"Hg.

The standard volume V' of CO_2 , will therefore be, $\frac{AW_2}{100W_3 S}$.

This volume is (a)% (from the volumetric analysis) of the total volume of gas delivered by the producer. The total volume of standard gas from the analysis is therefore:-

$$V = \frac{AW_2}{aW_3 \times S} = \frac{A (PW - P_6 W_6)}{.1161 a (3/11A + 3/4E + 3/7F)} \text{-----3}$$

The fact that the gas per lb. of coal so nearly checks in the tests computed where the composition of the coal and gas was practically constant, justifies the choice of formula (3), for the volume of gas.

ITEMS 120 - 125:-

Volumetric analysis

$\text{CO}_2 = a \%$

$\text{CO} = b$

$\text{O}_2 = c$

$\text{H}_2 = d$

$\text{CH}_4 = e$

$\text{N}_2 = f$

Analysis by weight

$A\% = \frac{.1161a}{W}$

$B = \frac{.07262b}{W}$

$C = \frac{.08418c}{W}$

$D = \frac{.0053d}{W}$

$E = \frac{.04278e}{W}$

$F = \frac{.074f}{W}$

Where W = the specific weight = Item 103.

ITEM 126:-

The grate efficiency is 100 times the ratio of the total B.t.u. in the fuel, minus the B.t.u. in the fuel lost thru the grate, to the total B.t.u. contained in the fuel.

Therefore:-

$$E = \frac{100WB - W_2C \times 14540}{WB} \text{ in which } W = \text{the total weight of dry coal,}$$

B = the B.t.u. per lb. dry coal, W_2 = total weight of ash and refuse, and C = the % carbon in ash and refuse.

ITEM 127:-

The hot gas efficiency is 100 times the ratio of the

total heat of combustion of the gas, plus the sensible heat of the gas, to the total heat in the fuel. Therefore:-

$$E = \frac{\{WB + C_p W_3 (t - 62) + W_2 [1116 + .6 (t - 212)]\}}{W_4 B_4} 100$$

In which W = total volume of standard gas, B = B.t.u. per cu.ft. standard gas, C_p = Specific heat, W_3 = total weight of gas, t = temperature of gas leaving producer, W_2 = weight of moisture in gas, 1116 = total heat above 62° of steam at atmospheric pressure, W_4 = total weight of dry coal, and B_4 = B.t.u. per lb. dry coal.

ITEM 128:-

$$E = \frac{WB \times 100}{W_4 B_4}, \text{ in which the notation is the same as in}$$

Item 127.

HEAT BALANCE:-

DEBIT.

ITEM 2 = $W \times .24(t - 62)$ where W = air per lb. of coal, and t = temperature of fire room.

ITEM 3 = $\frac{W (H - 1070)}{W_2}$ where W = wt. of water carried in by the air, H = total heat in 1 lb. saturated steam at fire room temperature, and W_2 = total weight of dry coal.

ITEM 4 = $\frac{WM (t - 62)}{100 W_2}$ where W = total weight of coal as fired, M = % moisture in coal, t = fire room temperature, and W_2 = weight of dry coal.

ITEM 5 = $.24 (t - 62)$ where t = temperature of fire room.

ITEM 6 = $\frac{W (t_2 - 62)}{W_2}$ where W = weight of water evaporated, W_2 = wt. of dry coal, and t_2 = temperature of feed water. In test #15 this item was = .989W, where W = the weight of steam fed to producer, and 989 is its total heat above 62°.

The 989 was obtained as follows:-

The well known equation for the total heat in moist steam is $H = q + xr$ in which, H = the total heat, q = the heat of the liquid, (above 62°F in the above case), x = the quality, and r = the latent heat. It was assumed that the steam quality was 80% and substitution gave the above figures.

CREDIT.

ITEM 1 = $C_p W (t - 62)$ where C_p = specific heat, W = weight of standard gas per lb. of coal, and t = Temperature of gas leaving producer.

ITEM 2 = $\frac{MW}{100} [0.6(t - 212) + 1116]$ where M = % moisture in gas, W = weight of gas per lb. of coal, and t = temperature of gas leaving producer.

ITEM 3 = VB where V = volume of gas per lb. of coal, and B = B.t.u. per cu.ft. standard gas.

ITEM 4 = $\frac{WC \times 14540}{100W_2}$ where W = total weight of ash, C = % carbon in ash, and W_2 = total weight of dry coal.

ITEM 5 neglected.

ITEM 6 = $\frac{W (t - 62)}{W_2}$ where W = total weight of overflow water, t = temperature of overflow and W_2 = wt. of dry coal.

ITEM 7 = Sum of items on debit side -(Item 1 + Item 2 + Item 3 + Item 4 + Item 6)

CONCLUSIONS:-

A glance at the result sheet will show, that in the tests tabulated, the water decomposed, per lb. of air was only about 1/7 the theoretical amount, and that the temperature in the producer ran considerably above 1650. It is, therefore, highly probable that the water reaction followed the equation:-

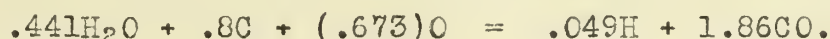


A comparison of the gas analyses with the one when the above reaction takes place, shows that they nearly correspond, with the exception of the presence of the CO₂ in the experimental analysis. This can be explained by the fact that the reaction:-



is taking place as well as the reverse one.

From equation (11) under "Theory" the following things may be obtained for a coal containing 80% carbon:-



Composition of gas:-

CO	-----	25.6 cu.ft.	=	39.5 %
H	-----	9.3 cu.ft.	=	14.3 %
N	-----	<u>30.0</u> cu.ft.	=	<u>46.2</u> %
Total		64.9		100.0

B.t.u. in gas per lb. of dry coal = 11150

B.t.u. in gas per cu.ft. of gas = $\frac{11150}{64.9} = 172$

Volume of gas per lb. of dry coal = 64.9

Air required per lb. of dry coal = 38 cu.ft. = 3.08 lb.

Water required per lb. of air = $\frac{.441}{308} = .143$

Efficiency = $\frac{11150 \times 100}{.8 \times 14540} = 95.5$

The above development, of course, takes no account of losses, and

in practice the hot gas efficiency could not be expected to run above from 85 to 90 percent. Comparing this with the efficiency obtained in the experiments, it can be seen that the latter is in nearly every case low. Referring to the curves plotted between load and efficiency, it may be seen that the latter rises as the load is decreased. As the hot gas efficiency varies with the moisture in the gas, the cold gas efficiency offers the better means of comparison, and as would be expected, the points fall on a smoother curve. This comparison may be legitimately made because the analyses show that the coal used each time was practically identical with the others.

It may be noticed that the amount of water supplied per lb. of air is in every case in excess of the theoretical amount, while that decomposed falls far short of it, thus allowing the temperature to be high. The reason for this is difficult to see. A curve has been plotted between cold gas efficiency and water decomposed per lb. of dry coal, but the points fall very irregularly, and no very satisfactory conclusion can be drawn, although the general trend seems to indicate a rise in efficiency with the amount of water decomposed.

Inspection of the heat balance will show that the radiation losses in test #15 was much greater than in the others. This was due partly to the fact that the vaporizer was blanked off and no water used in it. Heat was also being put in all the time in the steam, and the two things working in conjunction caused the producer to be rather warm.

It was found that by cleaning from the bottom before poking from the top reduced the amount of unburnt coal taken out

with the ash and made the grate efficiency higher. It was not very high at the best.

The producer in question was rated at 8000 cu.ft. of gas per hour. The usual rating is 16 lb. of dry coal per hour per sq. foot of fuel bed, and this for most infusible ash. Since the area of the fuel bed, was 1.767 sq.ft., and the gas per lb. of coal was about 80 cu.ft. a rational rating would have been 2200 cu.ft. per hour. A glance at the efficiencies will verify this view.

The fact that the gas at the Junker calorimeter was extinguished at each firing, leads to the conclusion that the producer would not have much show in commercial work with the present arrangement for this purpose. This could be remedied by installing a bell hopper so that coal could be fired without admitting such large quantities of air.

For the best results it was necessary to poke the fire from the top about every two hours or less. If this was not done clinker formed, and channels were produced thru the fuel bed thus preventing proper contact between air and carbon.

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